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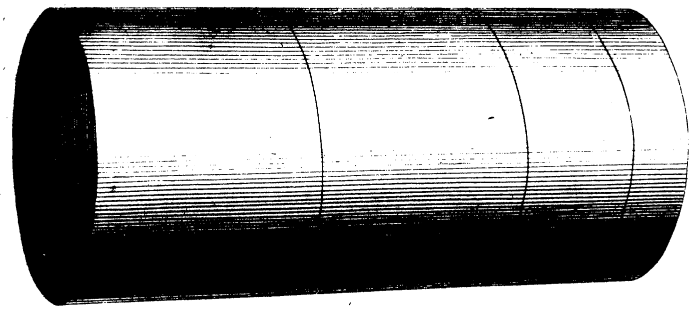

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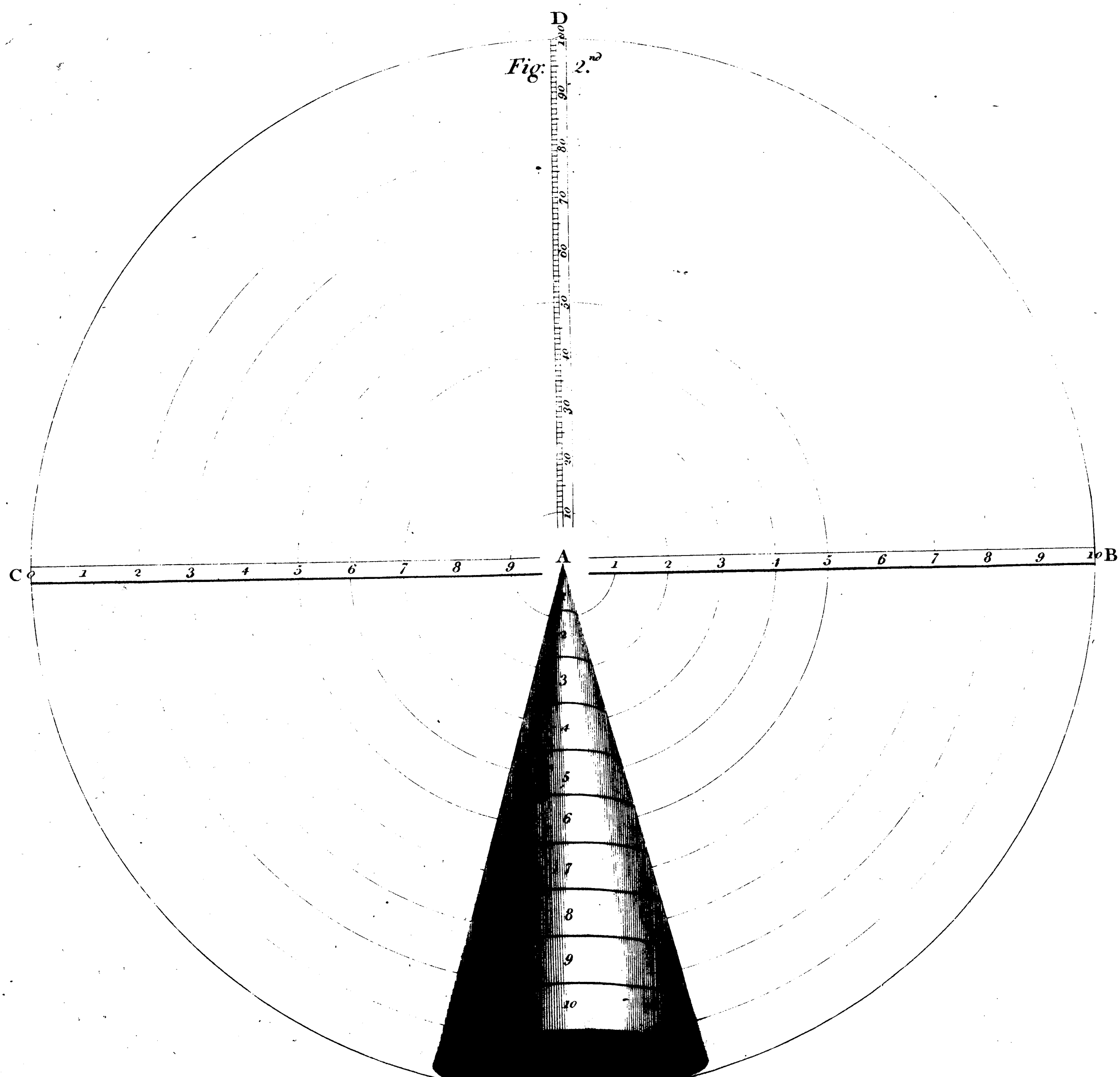

T. Foot sculp.

OBSERVATIONS

ON THE EFFECTS WHICH

CARRIAGE WHEELS,

WITH

RIMS OF DIFFERENT SHAPES,

HAVE ON THE ROADS;

RESPECTFULLY SUBMITTED TO THE APPROBATION OF THE

BOARD OF AGRICULTURE,

AND TO THE

CONSIDERATION OF THE LEGISLATURE.

BY

ALEXANDER CUMMING, Esq. *F. R. S. Edin.*

LONDON:

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1799.

OBSERVATIONS, *&c.*

[Mr. CUMMING *having left with the* SECRETARY *of the Board of Agriculture, for the perusal of Lord* SOMERVILLE, *a Copy of his* ESSAY *on this Subject, it was read at the next Meeting, and so much approved, that the President applied for leave to publish it in the* COMMUNICATIONS *to the* BOARD; *or such part of it, as Mr.* CUMMING *might think proper: in answer to which application the following Letter was received.]*

To the Right Hon. Lord SOMERVILLE, *President of the Board of Agriculture.*

MY LORD,

IT is flattering to me that the Essay, which I left for your perusal and observations, meets with your approbation, and is thought worthy of a place among the valuable Communications of the Board of Agriculture.

Although it has been printed for more than two years, it was not my intention to bring it to public view, till it had been submitted to the consideration of Parliament; that, if approved, it might receive that sanction and support, which alone could bring the practice it recommends, into general use, and render it of essential benefit to the public.

But as this Essay can only be considered as the *basis* of a system for the preservation and improvement of roads, private as well as public, I have bestowed much thought, for some time past, on the means that would best answer, to gain all the advantages that might reasonably be expected from a *voluntary* and universal use of cylindrical wheels; but as the attention of Parliament is at this time engaged in matters of such importance, as in a great measure to exclude the consideration of domestic improvements, no attempt has been hitherto made to bring it under discussion.

It was on that account that I declined having this Essay inserted in the last volume

of the *Communications* to the *Board* of *Agriculture*, with the other Essays on Roads, although the late President applied to me repeatedly for that purpose: but I cannot resist the very polite manner in which your Lordship has proposed to have the whole or part of it inserted in your next volume. The readiness of your Lordship, and the Board at which you preside, to recommend it to the notice of Parliament (if it should be found deserving), and the attention that such recommendation would receive, cannot be doubted; I therefore most cheerfully agree to have the whole Essay printed with the other Communications to the Board of Agriculture, and shall prepare in a few days a copy for that purpose, with some additional explanatory notes.

It was my wish to write in such plain language as might be understood by men of common understanding, without any great knowledge of science; but I have not the vanity to think, that my success has been such as to render further elucidation unnecessary; I have, therefore, prepared an apparatus, by which every circumstance that is asserted in this Essay is proved experimentally; the different powers required to draw the same load with conical and with cylindrical wheels are shown; the derangement which the conical wheel occasions, in the materials of the road, is rendered obvious to the eye, and undeniable proof given, that the additional power required to draw the same load on conical wheels, arises from the partial dragging that unavoidably attends the conical shape of its rim.

If an exhibition of these experiments should be wished for by your Lordship, and any of the Members of the Board, I shall have much pleasure in exhibiting them at your office, at any time which you may please to appoint, giving me one or two days previous notice; and if the result of the experiments should be judged of any importance, the description of the apparatus, and an account of the experiments, may become the subject of another paper, and afford me an additional opportunity of expressing my high respect for the Board of Agriculture, and how much I have the honour to be

Your Lordship's

obedient humble servant,

ALEX. CUMMING.

Pentonville, March 10th, 1799.

Observations on the Effects which Carriage Wheels, with Rims of different Shapes, have on the Roads; respectfully submitted to the Approbation of the Board of Agriculture, and to the Consideration of the Legislature. *By* ALEXANDER CUMMING, *Esq. F. R. S. Edin.—(First printed in* 1797.)

TO THE READER.

LATE in the last Session of Parliament, (1796) Mr. Cumming had occasion to attend a Committee of the House of Commons, then deliberating on the means of relieving carriages of a certain description from the controul of weighing engines, and subjecting them to an additional toll of fifty per cent. in compensation; and being asked his opinion as to the equivalency of the additional toll proposed, to the damage which the roads might sustain by the exemptions; he stated as his opinion, "that the damage "would chiefly depend on the construction of the wheels that were used; that the co- "nical or tapering rims now universally used, were extremely destructive; and that a "flat cylindrical rim would be very advantageous to the roads." But being then unprepared, and judging that what he might have to say would be too long for their report, he declined entering more fully upon the subject at that time. But the high respect due to the legislature, and an earnest desire of contributing all in his power to the accommodation of the public, induced him to the investigation that composes the following essay; and if what he has written, should by some be thought too prolix, let it be imputed to a desire of overcoming prejudices established by long and universal usage; by representing the object in various lights.

But seeing as he proceeded that a large field of inquiry presented itself, and that his essay was extending beyond the intended limits: he found it necessary to confine his observations as much as possible to the immediate and contrary effects which the conical and the cylindrical rims of broad wheels must have upon the roads.——In that light therefore, the following essay is offered—not as treating generally of the construction of wheels or wheel carriages, which undertaking would be yet much more extensive.

Although very great advantages may be gained by an immediate adoption of cylindrical rims, more especially to the broad wheels of heavy carriages, yet many regulations will be necessary to extend these advantages to the utmost limits of which

they are susceptible, and to diffuse the effects of cylindrical rolling, more equally than at present, over the whole surface of the roads.

Much may be done by illustrating, by the most familiar means, the several properties and effects of the conical and cylindrical shapes; and contrasting them by simple experiments and ocular demonstration. It will also be necessary that owners of waggons be fully informed of all such matters, and of the privileges and exemptions to which a compliance with such regulations as the wisdom of the legislature may suggest, would entitle them; and that all those employed in building heavy carriages, be made acquainted with the best principles, and most approved construction; by which means, the profound judgment of men of science, and the practical knowledge and dexterity of the artist, may be united for the public good:—and probably a system might be adopted which would not only effectually answer all those purposes, without additional expence to the public, but also produce a considerable yearly saving to the public, and relieve the farmer and the waggoner from inconveniencies to which they are at present subjected, to the disadvantage of the public, as well as of themselves.

N. B. The numbers enclosed in parentheses ( ) refer to the preceding paragraphs on which the subject matter of the present more immediately depends.

Pentonville, 1797. ALEXANDER CUMMING.

OBSERVATIONS, &c. &c.

1. Although the following observations are applicable to wheels of every denomination, they more particularly apply to the broad wheels of waggons, and other heavy carriages, because in them the effect is greater and more perceptible.

2.—The properties of all wheels, so far as regards this inquiry, depend upon their affinity to the cylinder, or to the cone: and in order to shew the nature and tendency of each class, it is necessary briefly to state such properties as unavoidably arise from the shape of these bodies.

3.—THE CYLINDER, having *all its parts of equal diameter*, will, in rolling on its rim, have *an equal velocity at every part of its circumference*, and *necessarily advance in a straight line.*

4.—And as all the parts of the rim have an equal velocity, none can have a tendency to drag forward, or to retard the progress of the others: they all advance with one consent, without the rubbing of any part on the surface on which they roll.

5.—As there is no rubbing, there can be no friction; and consequently, a cylinder perfectly round, hard, and smooth, would roll on a surface perfectly level, hard, and smooth, *with the least possible resistance,* however great its weight, or the pressure on its rim.

6.—It therefore follows, that all the power that is employed in drawing forward a cylindrical body, in a straight line, on a compressible substance, is ultimately applied in compressing, smoothing, and levelling the substance on which it rolls.

7.—The rolling of a cylindrical body, therefore, (5) can have no tendency to alter the relative situation or position of the parts of materials on which they pass, nor any how to derange them, but by a progressive *dead pressure* to consolidate, level, and smooth them.

8.—And the binding materials over which they pass being thus brought more within the sphere of mutual attraction, and into more perfect contact, are left in a state more favourable to concretion and induration; and, in every respect, better qualified to resist violence, and to protect from rains, the *softer materials* which they cover; and *they*, being thus kept dry, are the better enabled to support the crust that protects them: and thus the internal and external parts of the roads derive a mutual advantage.

9.—These properties of the cylinder are practically confirmed by the effect which frequent rolling with a cylinder has on gravel walks; it renders them compact, hard, smooth, and impervious to rains; and consequently, secure against the devastations of hard frosts. Nor does it break or grind the gravel, more especially after the first time of rolling, when all the parts are laid flat and smooth.

10.—If a cylinder be cut into several lengths, as represented in Fig. 1, Plate XVIII. each part will possess all the above properties; and if the rim of a carriage-wheel be made exactly of the same shape it must necessarily have the same tendencies; and its rolling will have the same effect on the roads that cylindrical rollers are observed to have on garden walks*.

* The advantage of increasing the breadth of cylindrical rims are too obvious to be insisted on: as the surface which sustains the pressure of the load is increased, the pressure on each part of it is

11.—When wheels with *cylindrical rims* are connected by an axis, the tendency of each, being to advance in a direct line, they proceed in this connected state with the same harmony and unity of consent that exist in the parts of the same cylinder; with the same facility of motion (5) so favourable to the cattle; and with all other properties that have been stated as favourable to the roads: *there is no more friction or resistance in this connected state of the pair of wheels* that are applied to the same axis, *than if each rolled separately or unconnectedly.**

12.—*All these properties of the cylinder depending wholly upon the equality of every part of its diameter, and consequently upon the equality of the velocity of every part of its circumference, are peculiar to it; and it is impossible to gain equal advantages with any other shape of the circumference of a wheel.*†

13.—But as *conical rims* have been universally preferred for a series of years, it is natural to suppose that there were obvious reasons for such preference. Let us then endeavour to investigate the properties that must necessarily arise from the shape of the cone; and see from them how far the *consequent effects* can justify the preference so long given to the conical rim.

14.—The Cone diminishing gradually from its base to its point, the velocity of every part of its circumference in rolling on an even plain will be diminished *as the diameter*; and at the very *point*, where there is no visible diameter, there will be no perceptible motion, the cone revolving round *it*, as a fixed point or centre; we shall therefore, call it *the conical centre*, to distinguish it from the axis of the cone.‡

15.—Let a cone have races or circles marked on its circumference, dividing the

diminished; and consequently the power of crushing the materials on which they roll: but as it may not be so easy to conceive, why increasing the breadth of any wheel should be hurtful to the roads or to the horses, it may be necessary here to observe, that none of the objections that apply to broad *conical* wheels, do in any degree apply to broad cylindrical ones.

* The contrast to this will be seen when we consider conical wheels applied to an axis.

† The globular is the only shape that can even in theory advance in a straight line with the same facility that the cylinder does, but the globular form rolling on a flat hard surface, touches only in *a point*; and in rolling on compressible substances, it partakes of the disadvantages of the cone: whereas the cylinder bears equally on the whole breadth of its rim; which gives it superior advantages for the wheels of carriages, to any other possible shape.

‡ In treating of conical wheels, *the conical centre* is only an imaginary point, and must not be mistaken for the centre of the wheel, which is the axis of the cone.

whole length into ten equal spaces, as represented in Fig. 2; if it be made to roll on a smooth regular horizontal surface, the circles that are on the circumference of the cone will trace on the horizontal surface other circles; also at equal distances; the circumference of each, representing the space described by the part of the cone that passes over it in one revolution round the conical centre, and the comparative spaces in any number of revolutions.

16.—But the circumference of each circle is as its distance from the centre, and the velocity of each part of the cone is also as its distance from the centre (14): therefore the space described by each part of the cone in rolling round its point is as the velocity of such part; and the cone will roll *in this direction* without rubbing or friction and with the same facility that the cylinder does in a straight line (5).

17.—But if the cone be made to advance in a straight line, the natural velocities of its several parts will *not* be as the spaces which they are compelled to advance (16); therefore a rubbing and friction will take place at its circumference, from the different velocities of its parts, which must render the draught heavier.

18.—Let a straight line be drawn from the centre of the circles in Fig. 2, to the circumference of the largest, and divided into a number of equal parts, suppose 100, and numbered progressively from the centre, A. to D. Each part of this scale will express the velocity of that part of the cone that rolls immediately over it; and thus may be found the difference of velocity of any two parts of the cone (16).

19.—EXAMPLE: If the difference of velocity of the greatest and the smallest parts of the circumference of that piece of the cone which is marked No. 10, be desired; the scale shews the velocity of the greatest part to be 100; and of the least part 90; and if each part was to advance according to its natural velocity (16); the greatest would run ten miles whilst the smallest part would only advance nine; which, in fact, happens when they roll round the conical centre;* but, *when made to advance in a straight line*, the smallest part of the rim is necessarily dragged one mile in ten, to keep pace with the largest part.†

* This may be seen by the scale A. B. which shews the comparative spaces described by the different parts of the cone in any number of revolutions round its point or conical centre A.

† If the numbers on the scale A. B. be reversed as at A. C. they will express, in decimals of the whole progress (15), the quantity of dragging at every part of the cone when advancing in a straight line, and rolling according to the natural rotatory velocity of the largest part of it.

20.—And if the cone be supposed to be cut, and separated at the several races marked on its circumference, and each part to form the rim of a broad wheel; the separated parts will regard their conical centre as when united with the others: and if rolled in this separated state on a level plain, each part of the cone would roll in the same circle round the conical centre that it did when all the parts were connected. And the difference of velocity of the parts of each wheel, and consequently, the friction and resistance at its rim, when advancing in a straight line, may easily be determined. And it will clearly appear that the rubbing at the rim of each, will in passing through a given space, be increased as its diameter is diminished (19), and as its breadth is augmented.

21.—EXAMPLE: In the part of the cone marked 5, the greatest velocity is 50, the least 40; so that with these velocities the larger part of the wheel would advance five miles, whilst the smaller would only advance four (16); but, *when moving in a straight line*, the smaller part of the conical rim must necessarily advance as far as the greatest part, and must consequently be dragged *one-fifth of all* the way it goes.

22.—If we take yet a smaller part of the cone, No. 3, its greatest and least velocities are to each other as 40 to 30, or as 4 to 3; so that a wheel of this shape and proportion must have the smallest part of its rim dragged on the surface of the road *one-fourth* of all the way it goes; and daily experience shews how much the *dead drag* of one wheel retards the progress of a carriage; and by analogy, we may judge of the effect of a constant although partial drag, on all the wheels of a heavily loadened waggon.*

23.—But the evil arising from this rubbing at the rim of conical wheels is not confined to the increased labour of the cattle only; the *greatest efficacy is also given to their increased exertions* in destroying the hardest and most valuable materials of the roads: the largest part of the wheel dragging forward the smallest, and it with equal force resisting, there arises an action and a counter-action, and the largest and the smallest parts of the rim advancing with different velocities, and pressed

* If a waggoner were compelled by any regulation to travel with one wheel constantly dragging, he would willingly pay an ample consideration to set it at liberty. And if he were aware that each conical rim has a constant though partial drag, it cannot be doubted that he would gladly be relieved from this unnecessary labour of his cattle, by altering the shape of the rim, and submitting to such regulations as must ultimately tend to the improvement of the roads, and to his own immediate advantage, by relieving his cattle from unnecessary exertion.

by the weight of a heavy load, become alternate fulcrums to each other, for the destroying and grinding the hardest materials that can be procured.

24.—Whoever takes the trouble of inquiring into the requisites of a well-constructed pulverising mill, will find them combined in the conical broad wheel of a heavy-loaded waggon.

25.—The impalpable powder that is thus formed on the surface of the roads, when in a dry and rigid state, is by the least agitation raised into clouds of dust, to the great annoyance of the traveller, and all who live near the road; to remedy which in some degree, watering is used near the metropolis; which, keeping the roads moist, they more readily admit water, which anticipates and increases the effects of wet seasons.

26.—When the roads are moist, pliant, and compressible, the effect of the *conical rim* is altered, but not less destructive: on the approach of wet seasons, the body of pulverised matter that lies upon the more solid gravel which supports the wheels, is soon mixed with water, and forms a body of sludge which excludes air, and keeps the roads in a constant state of moisture: this soon renders the interior parts of the road so moist and pliant that the pressure of a heavy waggon wheel will make the whole breath of *its conical rim* to apply flatly; and press hard upon the more solid materials which lie under the sludge; the parts of which being now in a state more susceptible of altering their relative positions, comply with the motion of such parts of the wheel as immediately press upon them; and the relative situations of the parts that form the crust of the road, are as much altered among themselves, as the velocity of the parts of the rim differ from each other (21, 22); and thus, all former concretion is destroyed, induration prevented, and the materials which form the crust of the road are left in a broken unconnected state, ready to imbibe the water which the sludge on its surface supplies constantly and abundantly: and by this means the most destructive effects of wet seasons and subsequent hard frosts are introduced in a manner as destructive and certain, as it is deeply concealed from observation.—How different is this from the consolidating effects of cylindrical rims under the same circumstances.

27.—In rolling on paved streets nothing can be conceived more calculated for their destruction than the *conical rim* of a broad wheel. Let us suppose the *largest* part of the circumference of the broad wheel of a waggon to bear upon one stone of the pavement, and the smallest part of it upon the adjoining

stone, the one will be pushed backwards and the other dragged forwards (23) by the force of the horses that draw the carriage: and if this force is sufficient to open the joint between them so as to admit water, the mischief is done; a wet joint will imbibe more water; this softens the gravel with which the paving is laid; and leaves it less able to resist the next effort; by which the joint gets more loose, and admits water sufficient to *float* and *discharge the gravel*; which ultimately undermines the paving, and furnishes the surface of the streets with that copious supply of new dirt, which may be seen very soon after it has been completely washed by heavy rains.—This effect of conical wheels acts in so latent a manner, that it appears to have totally escaped notice; *but the cylindrical rim will not only prevent all this mischief, but will also improve the streets,* by producing the effect of the rammer wherever the wheel passes.

28.—Several other disadvantages of less importance attach to the *conical rim*; a constant divergency from the rectilineal direction, makes the wheel to press continually against the linch pin, and ready to fly off the axis when the linch pin is lost or broken (20). The same divergency occasions a twisting of the nave on the axis, which increases friction. And if the *box* is gulled or badly fitted on the axis, it will occasion the hind part of the wheels to run closer to each other, than the front, which makes it rub hard against the *inside** of deep ruts, and throw up much dirt towards the middle of the road, which greatly obstructs the progress of the carriage, and increases the labour of the cattle; none of which inconveniencies attend the cylindrical rim.

29.—It may be thought extraordinary that no good qualities should here have been imputed to the conical shape of a wheel, although sanctioned by universal preference for so many years: but if any do belong to it, except only the flat bearing of its whole breadth, the Author of this Essay has not been so fortunate as to discover them. He will in a subsequent part, attempt to shew the reasons that first introduced them, and that occasioned the preference so long and so unjustly bestowed on them; but it would here divert the attention from what is of more moment to the immediate inquiry.

30.—Let us then, to assist the memory, and to bring the comparative merits of *cylindrical* and *conical rims* into one point of view, briefly recapitulate the properties that *inseparably* belong to *each:* and first of

* *Inside.* Here means the side next the carriage.

THE CYLINDRICAL RIMS.

31.—1. Naturally advance in a straight line (3);

2. Have no friction or rubbing at the circumference (4, 5);
3. No rubbing against the sides of deep ruts (11, 28);
4. No throwing up of dirt by the hind part of the wheel (11, 28);
5. Do not increase friction on the axis (3);
6. Have no pressure against the linch pin (3);
7. The only resistance to their rolling in a straight line is from compressing, smoothing, and levelling the substances on which they roll (5, 6);
8. They have no tendency to displace, derange, break the texture, or retard the concretion and induration of the parts on which they roll (7);
9. Their frequent rolling on compressible substances renders them more compact, smooth, hard, and impervious to water; and leaves them in a state more favourable to concretion and induration; and by keeping the *interior* and softer parts dry, *they* are the better enabled to resist violence, and to support the crust that protects them (7, 4);
10. They have no tendency to open the joints in paved streets (27); but, on the contrary, to improve them by producing the effect of ramming the stones on which they pass, by the *dead pressure* produced from the uniform velocity of all the parts (7);
11. And they advance *in a straight course* with the least possible resistance (5), and with advantages superior to any other possible shape (12);
12. They serve equally to improve the roads, to relieve the cattle, and to preserve the tires of the wheels.

And all these properties are as peculiar to, and inseparable from the CYLINDRICAL SHAPE as they are favourable to the roads and to the cattle.

CONICAL RIMS.

32.—1. They naturally roll in a circular direction, round their conical centre (14, 20);

2. A constant force is required to confine them to a straight course (17);

3. When constrained to move in a straight direction, a rubbing and friction take place at the rim (17 to 22);
4. They increase friction on the axis (28);
5. They occasion a rubbing against the sides of deep ruts (28);
6. And a throwing up of dirt from the hind part of the wheel (28);
7. In dry weather they pulverise the best materials (23);
8. Which occasions much sludge in wet seasons, and much dust in dry (26);
9. In a compressible state of the roads they derange and break the texture of the parts, and leave them in a broken state ready to imbibe water, which introduces all the ruinous effects of wet seasons and severe frosts (26);
10. They promote the destruction of paved streets and causeways, by forcibly opening the joints and admitting water under the stones, which ultimately floats and discharges the gravel, loosens the stones, and sinks the pavement into holes (27);
11. They increase the labour of the cattle;
12. And promote the wearing of the tires of the wheels by their constant dragging and grinding on the roads, none of which take place with the cylindrical wheels.

Such are the effects that unavoidably arise from the conical shape, and they seem as much calculated for the destruction of the roads, as those of the cylindrical wheels are for their preservation and improvement.

33.—And, seeing *that the cylindrical rim is the most favourable that can possibly be adopted for the preservation and improvement of the roads* (31), and that *the conical is the most destructive* (33), a certain advantage must be gained by using the former instead of the latter; and as this advantage must be in proportion to the space or surface that is rolled; it cannot be thought excessive to rate that difference at *one shilling for every acre of road that is rolled with an improving roller, instead of an impairing one.*

34.—*Let us then see what may be the probable amount of the advantage that may thus be gained to the nation yearly, by adopting cylindrical rims for the wheels of such waggons only as travel the turnpike roads.*

35.—The number of waggons in England is upwards of 96,600; and supposing that a tenth only of that number, is employed on the turnpike roads; and a fourth

of that tenth, or a fortieth of the whole, have wheels twelve inches broad; and of the remaining three-fourths, that one half have wheels six inches broad, and the other half, wheels only four inches, the statement of the whole will be as follows:*

36.	Number of waggons employed on the roads - - -		9,660
	Waggons with 12 inch wheels - - - - - -	2415	
	Ditto with 6 inch wheels - - - - - - -	$3622\frac{1}{2}$	
	Ditto with 4 inch wheels - - - - - - -	$3622\frac{1}{2}$	
			9,660

37.—A wheel 12 inches broad, will, in rolling thirty miles, cover a space of 158,400 feet, and the four wheels of a waggon rolling a double surface will, at the same rate, in a day's journey, roll a surface of 633,600 feet, which is equal to the whole surface of four miles of a road thirty feet wide; and something more than fourteen and a half acres, but rejecting fractions, and taking fourteen and a half acres as the quantity, the result in acres will be as follows:

38.—	2415 waggons, with 12 inch wheels, will, in a day's journey of thirty miles, roll - - - -	35,012
	3622 waggons, with 6 inch wheels, will roll - -	26,259
	3622 waggons, with 4 inch wheels - - - -	17,506
	The number of acres rolled in a day by all the waggons - - - - - -	78,777

39.—And supposing all the waggons, at an average, to travel only ninety days in the year, they will roll a surface equal to 7,089,930 acres; which, at one shilling per acre, will exceed THREE HUNDRED AND FIFTY THOUSAND POUNDS per annum.

40.—But waveing pecuniary estimates; let it be remembered, that the quantity of surface that is rolled once yearly by the waggons that travel the roads of England, is equal to the *entire surface* of 1,948,880 miles of road thirty feet wide (37, 38). It is then of importance to inquire, whether the wheels that roll this very extensive surface, tend to improve or to impair it?†

* Allowing 9,660 waggons to travel the turnpike roads, there remains 86,940 of which notice will be taken hereafter.

† It is to be observed, that no notice is here taken of the waggons that are supposed to be employed for the purposes of agriculture, &c. nor of the immense number of carts, coaches, &c. that travel the public roads.

41.—The sovereign power of prejudice established by long usage, and universal adoption, would forbid an attempt to prove the unfitness of conical rims, if a desire of rendering a public service, and a knowledge of the abilities and dispositions of many members of both houses of parliament to promote improvement, and their unwearied attention to the good and comfort of the public, did not demand it as a duty, and afford every reason to hope that if any thing here offered is deserving their attention, it will receive ample discussion, and that such regulations may be adopted, as will introduce a general and voluntary use of cylindrical broad wheels to all such waggons and carts as travel the turnpike roads: and that may, not only introduce such wheels, but also diffuse the effect of their rolling more equally on every part of the surface; by which means the roads in this country may be improved, without additional expence, and even at an expence greatly diminished, to a degree of perfection much exceeding general expectation.

42.—With a view to remove such prejudices, *we now proceed to shew, that, in the early state of wheel carriages,* CONICAL RIMS *were introduced as matter of accommodation to enlarge the body of the carriage, without any attention to the immediate and destructive effects which they have on the roads.*

It is pleasant to look back and view the primitive state of the roads and carriages in this kingdom, and to trace the gradual improvements which they have undergone within the last half century, and the increase of wealth, comfort, dispatch, and additional time for business, which the inhabitants of the kingdom enjoy from the improvement of the former, and the increased number of the latter.

43.—SLEDGES probably were the first carriages used; and, as an improvement on them, wheels were applied, to diminish the friction on the surface of the roads.

44.—The first wheels that were applied to carriages were *fixed on the axletree,* which turned with them, so that the axis must necessarily be straight, and the wheels at right angles to it, and parallel to each other; and to give the whole breadth of the rim an equal bearing on a flat surface, *they must necessarily have been cylindrical.*

45.—In remote parts, where many concurring circumstances retard the progress of improvement, these original carriages may yet be seen; and an attentive observation of the primitive state of the roads as well as of the carriages may throw much light on the subject of this inquiry.

46.—The narrowness of the roads in their early state made it necessary that the

wheel carriages also should be narrow; and it is more than probable, that the carriages first used were only for the purposes of husbandry, and drawn by one horse.

47.—But in process of time it was found expedient to enlarge the carriages, and to increase the number of horses; but the narrowness of the roads, and the depth of the ruts that were already cut in them, made it necessary that the wheels of the new carriages should run in the tracks of the old.

48.—To gain the advantage of a wider carriage without making the wheels run wider, it became necessary to alter the original construction: the axletree was now fixed immoveably to the body of the carriage, and the wheels made to turn independently of each other on *its ends, which were made to incline, or bend*, downwards, by which means the wheels stood wider, or further apart at top than at bottom; and thus, room was gained for the body of the carriage without widening the track of the wheels.

49.—The axis being for this reason *bent* (48), and the wheels no longer standing parallel, it was necessary, in order to gain a flat bearing of the whole *rim*, to shelve it off towards the outer edge*, as much as the ends of the axis were bent from the straight line (48); and *thus the rim became conical.* Nor is it probable that any distinction was then made between the flat-bearing of a conical rim, and the flat-bearing of a cylindrical rim of the same breadth.

50.—When the wheels were made to turn on the ends of the axis, it was necessary, in order to get a steady motion of the carriage, to have a longish socket in the centre of the wheel, so fitted as to receive the end of the axis, and to turn on it freely and without shake. This socket is called the nave, and has all the spokes, or radii, inserted in it: the nave is commonly lined with metal, which lining is called the box or bush.

51.—The wheels now diverging at top, the spokes were inserted obliquely into the nave, so as to stand perpendicularly *when directly under the axis*, the better to sustain the weight of the load: and this oblique position of the spokes, giving to the side of the wheel that is the farthest from the carriage, a concave appearance, is called *dishing*: and thus it clearly appears, that the *bending of the axis occasioned both the conical rim* (49) *and the dishing of the wheels* (51); and as both were in-

* By *outer edge* is here meant the edge of the wheel farthest from the body of the carriage.

troduced as mere matters of accommodation, adapted to the then existing state of the roads, the narrowness of which demanded a bended axle (49), there is no great reason to believe that the bad qualities of the conical shape, nor the advantages of *dishing*, were originally adverted to.

52.—In process of time it was observed that *dishing* (or the oblique position of the spokes) added much to the strength and stiffness of wheels, even with very light timbers; and, on attentive examination, this construction was found to embrace all the properties of an arch.

53.—The bended axis necessarily demanding a conical rim (49) and a dished wheel (51), they were considered as inseparably connected with each other: and the advantages of dishing were considered as peculiar to the conical rim, which circumstance, together with an inattention to the destructive effects which it had upon the roads, have probably been the only reasons of *its* being so long and universally preferred to the cylindrical shape.

54.—But the *dishing* (or oblique position of the spokes) is by no means peculiar to conical wheels, and is equally applicable to cylindrical: and the advantages arising from this arcular construction of the wheel, are in some cases, applicable in a greater degree to cylindrical broad wheels, than to conical.

55.—*It does not then appear that any preference is due to the conical rim on account of the advantages that arise from dishing the wheels, since it is equally applicable to cylindrical rims. And, as none of the immediate properties or effects of the conical wheel entitle it to a preference, let us inquire whether there are any concomitant circumstances that can recommend it; or that forbid the use of the* CYLINDRICAL SHAPE.

56.—The adoption of a cylindrical form will necessarily require a *straight axis*, (44) and no other alteration whatever in the construction of the carriage will be necessary. But as the straight axis would make the wheels run equally wide at bottom as at top, the axis must necessarily be longer, and the track of the wheels wider, to preserve the same room for the body of the carriage.

57.—We are therefore to inquire, whether independent of the immediate effect which the rim of the wheels may have on the road, their running wider on it may be hurtful, on a more general view of all circumstances?

58.—By making the wheels run further apart on the road, the base on which the carriage stands becomes broader, and consequently it is not so easily overturned: and

in passing over obstructions, irregularities, or roughness on the roads, the agitation of the *centre of mean resistance* will be diminished, as the distance of the wheels is increased: and the resistance arising from the vis inertiæ; the fatigue of the rider; and the labour of the horses; will be diminished in the same proportion: all which considerations furnish additional motives for preferring the cylindrical wheel and straight axis.*

59.—Having thus totally failed in discovering any one argument in favour of the *conical rim* even from concomitant circumstances, let us endeavour to shew what has so long concealed *its destructive effects* with carriage wheels; more especially as universal preference was given to cylindrical garden rollers.

60.—FIRST, The garden roller being worked by men, and used singly, the difference of the natural tendencies and effect of the cylinder, and of the cone, were more exposed to observation, and more easily distinguished, than when a pair of wheels are connected by an axis (64).

SECONDLY, In drawing the conical roller on a straight walk, its strong bias to deviate from the *straight direction*, and the very considerable and constant exertion necessary to compel it to advance in a straight line, could not possibly pass unnoticed.

61.—THIRDLY, The rubbing and grinding of its smallest end, and the much greater exertion necessary to draw forward the conical than the cylindrical roller, must engage the attention of every rational being employed to draw them.

62.—FOURTHLY, That such has been the case is evident from the constant

* Much depends on a thorough understanding of this principle in the construction of wheel carriages, especially those for dispatch; and in constructing and loading ships. And there are not wanting instances where, from a want of due attention to this principle, one half of the effect in mechanical operations is totally lost, and the labour doubled.—The centre of mean resistance in carriages and in navigable vessels is nearly allied to the centre of oscillation in pendulums; but involves more considerations; and the application of this principle to wheel carriages would, in some instances, appear to be directly contrary to what it is in nautical concerns. In wheel carriages all deviations of the *centre of mean resistance* from the line of direct progress, are either horizontal or vertical, or compounded of both.—Deviations generally increase resistance; but in some instances vertical deviations may be promoted to advantage, but the horizontal never; and every circumstance that tends to prevent or diminish them is advantageous in the construction: attending to this circumstance alone, low wheels and long axles should be preferred; and the centre of gravity of the load should be kept as low as circumstances will permit; this will diminish the agitation, render the draught lighter, and the carriage more secure against overturning.

and universal preference given to the cylindrical garden roller, even for circular walks, where a *conical* roller would have been preferable.

And FIFTHLY, although the conical roller demands much more force to draw it forward, it never leaves the surface so close, compact, and smooth, as the cylinder does; the smaller end of the cone rubbing and dragging on the surface leaves it rough, loose, and unconnected. All which circumstances could not possibly escape the notice of the most ignorant or inattentive person whose bodily exertions were employed in drawing them; and whose attention was directed to their effect.*

63.—It might be thought that the superiority of the cylindrical over the conical garden roller might lead to an investigation of the comparative merits and effects of the cylindrical and conical wheels of carriages, but *the following circumstance has probably prevented it; by concealing from observation in wheel carriages, the real and natural tendency of the conical rim, and consequently its destructive effects.*†

64.—When *a pair of conical wheels* are applied to the opposite ends of an axis, they advance in a straight direction; APPARENTLY with the same ease and tendency that cylindrical wheels do (11). But how deceiving is this appearance, may be seen by an attentive perusal of what is said from paragraph 15 to paragraph 23; each wheel constantly endeavouring to roll round its conical centre; the one drawing to the right; and the other, with equal force, drawing to the left; they exactly counteract each other, and are thus compelled, to advance in a straight line. But although this rectilineal progress *appears to be natural and spontaneous*, it is quite the reverse;—

* The improving qualities of the cylinder are much more obvious than the destructive effects of the cone, which, in a great measure, accounts for the universal preference given to the former for garden rollers, and the readiness with which the latter shape was used to the wheels of carriages, when it was found convenient to have a bended axis (49).

† The use of rollers in moving large timbers, blocks of stone and marble, &c. is of very great antiquity; and these rollers being made of round pieces of timber, were naturally cylindrical, and this being the best shape in most cases, was used on all occasions.—When friction rollers were applied in machinery to remove or diminish friction, the cylindrical shape was universally used, and in many cases where the conical shape was more proper. It is more than forty years since I laid down rules for ascertaining the most advantageous shape for *friction rollers* under all possible circumstances, so as to have no rubbing or friction at their rim, and to move with the least possible resistance. But although the same principle applied equally to the rims of carriage wheels, as to friction rollers, it did not at that time occur to me, to be of so much importance to the public as it now does, the object of my pursuits at that time being totally different.

the natural tendency which so powerfully presses itself on the notice of him that draws the single conical roller (60), is here concealed by the intervention of the axis.—The two conical wheels counteract the divergency of each other; but the *destructive effect of each wheel on the roads, and its resistance to the draught, is in no degree diminished,* although deeply concealed from observation.—*And these reasons seem to account sufficiently, for the evils arising from the conical rims having so long escaped detection*: for, if waggons, like garden rollers, had been drawn by men, the increased exertion required with the conical rim, even on the best and smoothest roads, would soon have engaged their attention, and independent of all other considerations would have procured to the *cylindrical carriage wheel,* that preference which was so justly bestowed on the cylindrical garden roller.

65.—But it may be necessary to add some further reasons for being of opinion, that the bad effects of conical rims were either totally unobserved, or have remained without due investigation.

66.—The strongest argument that has been offered for continuing the bended axis, is, " That when the axis is straight, the lower side of its conical ends act " in the nave or " box of the wheel, as on an inclined plane, which gives it a constant tendency to press " against the linch pin, and to throw the wheel off the axis."—The remedy proposed, " was " to *make* the axis so, that the *under side* of its conical ends shall lie in a straight horizontal line."—This necessarily demands a bended axle and a conical rim, and plainly proves that they were not aware of the divergency and rubbing that unavoidably arises from the conical rim. For thus, *by bending the axis, there is a necessity of making the conical rim* (49); and the conical rim, unavoidably occasions a strong and constant pressure against the linch pin (64), so that in attempting to remedy a small imperfection originating at the centre; they not only increase the very imperfection which they meant to remove; namely, the pressure against the linch pin, but also add another, and much greater evil, at the circumference of the wheel (22); which cannot be removed *by any possible means* but by rendering the axis straight, and the rim cylindrical.—This demonstrably proves, that the tendencies and effects of the conical shape were not attended to by the advocates for the bended axis, which necessarily introduces the conical rim.

67.—Another strong ground for believing that none of the bad effects which attend the conical wheels have been attended to, arises from the great mechanical skill and heavy expences, that have been wasted in removing or diminishing the friction on the

axles of wheel carriages; which when compared with the friction at the circumference of the conical wheel, is totally undeserving of notice, from the very trifling comparative resistance which it occasions; and surely if the greater evil had been discovered, it would have claimed a priority of cure.

68.—And, moreover, the natural friction on the axis may be much abated by the application of oil, grease, &c. but there is no possible remedy for the friction, trituration, and increase of resistance that unavoidably take place at the conical rim, but by substituting *the cylindrical.*—All which concurring circumstances, it is presumed, may justify the assertion, that the cylindrical and conical rims have been indiscriminately used, without attention to any properties that are peculiar to either (and that so very strongly distinguish them); always preferring that rim which admitted of a flat bearing of the whole breadth of the wheel under the existing circumstances (44); and consequently, when the *axis* was straight, the rim was cylindrical; and with the bended axis the rim was necessarily conical (49) to give it an equal bearing on its whole breadth.

69.—It appears then, that in searching for arguments in favour of the conical wheels, we meet with nothing but additional reasons for preferring the cylindrical; and as the bent axis and conical rims were first used on account of the narrowness of the roads (48, 49) there can be no reason, at this time, for continuing the use of them for such carriages as travel the turnpike road only.—And the advantages which must result from the use of cylindrical wheels to them alone, will be more numerous and extensive than they have hitherto been stated, (58), arising from considerations that are not within the scope of our present inquiry.*

70.—In the preceding estimate (39) no allowance was made for such waggons as are used in agriculture, and that seldom come upon the public roads: but as every improvement of the private as well as public roads, must be a national benefit, we shall now consider what advantage may be gained on the private roads by the same means.

71.—Eighty-six thousand nine hundred and forty waggons are supposed to be employed for the purposes of agriculture (35), which is nine times the number that we have

* Nothing can be of greater advantage to the roads, than the diffusing the traffick of carriages equally on every part of its surface; this can never happen on convex (or barreled) roads. On them, *all carriages* keep on the very summit, which by that means is soon cut into ruts, that retain the water, and prevent its running down the sides as was intended; and by that means, the only purpose for making the roads convex is not only frustrated, but perverted.

supposed to use the turnpike roads (35); but as they do not keep constantly even upon the private roads, we shall suppose them to travel the roads only one day in a month; at which rate they will, *cæteris paribus*, roll one ninth more surface than all the waggons that travel the public roads, at the rate of eight days in the month; but let us suppose it only equal.

72.—The quantity of surface that would be rolled once in the year, by all the waggons travelling the turnpike roads in England, is equal to the entire surface of 1,948,880 miles of a road thirty feet wide (40), and taking an equal quantity for the private roads (71), the whole surface that is rolled yearly by waggon wheels on the public and private roads together, if uniformly diffused, would cover every part of the surface of 3,897,760 miles of road thirty feet wide; and in proportion as the length of road on which this traffick is supposed to be carried on is shortened, so much the oftener would it be rolled.

73.—The circumference of the terraqueous globe is computed at 24,900 miles, and if a road 30 feet broad was made quite round it, the waggons that travel the roads of England, would yearly roll every part of its surface 150 times (72); and

74.—Supposing *two* such roads made close to each other, and in every respect similar, as to formation, materials, exposures, &c. &c. but that the one is rolled by cylindrical, and the other by conical wheels, 75 times in the year, the former will be rendered more compact, close and impervious to water, each time of rolling; and in the end, will be so solid and hard, and its surface so close and smooth, and so free from dust in summer, and from sludge in winter, as neither to admit, nor to lodge water; which is the most effectual means possible of guarding against the destructive influence of wet seasons and severe frosts (31), and consequently of keeping the roads in continual good repair, at the least expence.

75.—But the *other road* being rolled also 75 times, *but with conical wheels*, they will, in dry seasons pulverise and destroy the best materials intended for the protection of the roads (23); and, in wet seasons, they alter the arrangement, and destroy the texture of the component parts of the crust, and leave them in a broken unconnected state, ready to imbibe water (26), which is constantly supplied by the sludge on the surface; which also effectually excludes the sun and air; and thus, the roads become rotten, and break into holes and ruts; and if a rainy autumn is succeeded by

severe frosts, they will raze to the foundation every part into which the water and frost have penetrated.

76.—Let any man of observation, who has had an opportunity of attending to the nature and repair of roads, and the expences attending such repairs, seriously consider all the above circumstances, and make his own estimate, of the number of men; quantity of new materials; and extent of labour and expence that would be yearly necessary, but more especially after a wet autumn and severe winter, to restore that road that had been rolled by conical wheels (32), to an equal state with the road that was rolled with cylindrical wheels (31), and he will, probably, make his estimate to exceed any that has been here stated (39).*

77.—It is also to be observed, that the latter road will not only be much more expensive than the former, but is liable for some months in the year to be in a state very disagreeable, and even dangerous to the traveller; and very destructive to the cattle; and at no time so pleasant as the road that is rolled with the cylindrical wheels; on account of the dust in summer (23), and the deep sludge in winter (26). And the draught of carriages upon it is at all times, but more especially after repairs, much heavier than upon *that road, which remains always unimpaired.*†

* When cylindrical and conical wheels are promiscuously used on the same road, their effects are so blended that it is impossible to distinguish or separate them. But if two similar pieces of road were made, and conical wheels only were allowed to travel the one, and cylindrical wheels the other; the difference of the two roads would soon prove the different effects of the cylinder, and of the cone; and the extent of the advantage that must arise to the public, by adopting the former, and rejecting the latter.

† It has been observed, that after very heavy rains, and where running waters have accidentally covered the surface of the roads, they were consolidated and improved thereby; this introduced the practice of washing roads, where running water can be procured, which is found very beneficial; but daily experience shews the advantage of removing sludge by other means, where running waters cannot be procured; and, although several reasons might be offered, why sludge is more penetrating and hurtful to the roads than pure water, such enquiry being foreign to our present subject, it is sufficient for our purpose, that daily experience and observation confirm the fact: if then, the removal of sludge from off the roads be so advantageous, surely any means by which its formation and accumulation may be prevented or diminished would be yet more advantageous than washing; and this can best be effected by discontinuing the use of conical wheels; which will diminish the dust in summer, the sludge in winter, and save the most valuable materials that incrust and protect the

78.—When the advantages of cylindrical wheels are fully proved, and universally known, there is no doubt, that thin, light, smooth rims, truly cylindrical, and broader than are now used, will be adopted universally for carriages of pleasure and dispatch, as well as for those of burthen; which, considering the immense number of carts, coaches, &c. &c. &c. in this kingdom, will add greatly to the advantages already stated: and the saving, that must arise in the repairs of *private roads*, from the use of broad cylindrical wheels, will very soon repay the first expence of making them of a sufficient breadth to admit carriages of any dimensions, which will totally obviate the only reason that now exists for using a bended axis and conical rim (46 to 49), and pave the way for an universal adoption of a straight axle and cylindrical wheel.

79.—The author of this essay is conscious that more is already said than is necessary, to enable men of extensive information and quick conception to form their judgment; and although he is aware, that the success of this attempt will wholly depend on their opinion, example, and support, he is nevertheless anxious to convince others, who are more immediately interested, but whose opportunities and capacities are more limited.—It will not be denied, that rolling with heavy cylindrical rollers would even in the first instance much improve the roads; but the expence attending this operation would exceed all reasonable bounds.—Let us then inquire, to what degree this end may be accomplished, without additional labour or expence?

80.—If the breadth of cylindrical wheels, and the length of the axles are made to bear a regular proportion to the number of draught horses; and the fore-wheels to run narrower than the hind, so as to roll a double surface, the roads formed flat; and proper regulations are made for quartering the roads; every waggon might be made as effectually to improve that part of the road on which it rolls, as if the horses had been

roads, as well as diminish the labour of the horses; in order to give an idea of the consumption of pit ballast used on the roads near the metropolis, the following statement is offered:

On an average of seven years, 10,961 loads of ballast have been annually laid on the roads belonging to the Hampstead and Highgate trust; and, as nearly as can be conjectured from observation, an equal quantity of sludge, or pulverised ballast, has been yearly removed:—from this circumstance, some idea may be formed of the importance of using every possible means for preventing this immense consumption of materials, which must in a few years increase in price, as they become more scarce, and the carriage of them more distant. The expence of each load of ballast laid on this road is from 5 to 6s. exclusive of labour in laying it, &c. The length of road in this trust is nearly 20 miles, so that the quantity of ballast at an average is 548 loads per mile annually.

employed for that only purpose: it is true that the rollers in this case are not so broad as might be desirable for that only purpose, but if the effect is not so extensive, it is more dense and compressive; and if the roads are made so nearly flat that carriages may with equal conveniency drive on every part of them, they will be more equally traversed, and more uniformly improved than at present; the destructive effects of the conical wheel will be evaded; and the draught of the horses made much easier.

Let us now see what sum would pay for the labour of the horses that may thus be made to roll the roads gratis, if they were employed for the only purpose of rolling them?

82.—The number of waggons supposed to travel the turnpike roads is 9,660, and allowing three horses at an average, for each waggon, their number will be 28,980; and taking an equal number for those waggons that use the private roads (72) the whole number will be 57,960; and supposing them to be employed only 90 days in the year, at 4*s.* per day for each horse, it would amount YEARLY to upwards of ONE MILLION STERLING; and it ought to be considered, that although the labour of the cattle is greater the first time of drawing on a new track, that it becomes light the next time; and if each individual contributes his aid, by once rolling on a new part of road, all the others are contributing equally to improve the road for him; and his good office is thus repaid, more than a thousand fold, by others who roll the roads for him.

83.—It is not meant to assert, that any of the estimates here offered are correct: but it is hoped they prove, that in every point of view, the object is of such magnitude and importance as to claim attentive investigation; and if what has here been advanced is found to merit the notice of those to whom it is addressed, Mr. CUMMING *will consider himself as peculiarly fortunate in having suggested an improvement, from which, every individual in the kingdom may derive accommodation, without additional expence to any; and by which, ultimately, a very considerable yearly saving and advantage may be gained to the public.*

POSTSCRIPT.

IN the foregoing essay, the conclusions are drawn from facts, and practical observations only. The author of it was for many years, in the earlier part of life, in the habit of reading all publications on subjects of this nature, and all others relative to mechanical and philosophical improvements; but of late years he has seldom found the

information which he could glean from compilations, to compensate for the drudgery of reading them; for this reason, he has for several years past, seldom read periodical publications; and if any thing relative to the subject of the foregoing essay has been published in that way, or in any other, it has escaped his notice; but he will thankfully receive any information on the subject, that can lead to improvement.

APPENDIX.

In the preceding essay, the effects of such wheels only, as have *an equal bearing of their whole breadth* have been considered, as all the laws that have been made for regulating the breadth of wheels, by the weight of the loaded carriage, have supposed and intended that all wheels should have; but as various means have been devised to evade these wise regulations of the legislature, by using wheels *that have* NOT *an equal bearing of their whole breadth*, the object of the following observations, is to shew in what manner such wheels as bear on a narrow part only of a broad rim, operate to the destruction of the roads, and to the manifest disadvantage of those who persist in using them.

PRELIMINARY OBSERVATIONS.

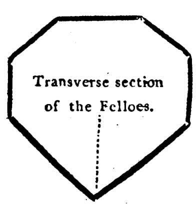
1. If earth, sand, gravel, or any other material, or combination of materials, of which roads are usually made, be laid on a flat pavement, to the depth of some inches, and confined at the sides, so as to be of a regular and equal breadth and depth, and of some considerable length; if the boards, or other substance by which the sides are confined be removed, and a flat wheel of the whole breadth of the bed or stratum of materials be made to roll on it length-ways, the pressure of the wheel will not only consolidate such parts as remain immediately under its track, but will also distend and spread a part of the materials to each side of the wheel, when it meets with no lateral resist-

ance, and by this means a part of the compressive force of the wheel is lost in forcing the materials *sideways* from under it.

2. If a wheel that is quite flat, and bears equally on its whole breadth, has this tendency of forcing the materials *sideways*; a wheel that is roundish across the felloes, or that has a high streak in the middle, must have a much greater tendency to spread or force them *sideways* from under the pressure of the wheel.

3. This lateral motion of the materials is always the greatest, on that side where it meets the least resistance; and the resistance will be the least, on that side where there is the lightest body of materials: and although this lateral motion of the materials in the road is not discernible to the eye, its effects become evident from the shape into which convex roads wear, by frequent and long usage; convex roads become flat, or hollow in the middle, and swell towards the sides; although, in repairing, the ballast is always laid in the middle, it is soon found to have shifted to the sides and extremities.

4. But in order to comprehend more clearly the manner in which this lateral motion takes place by wheels of an improper shape, and more especially on *convex roads* where the resistance is always less towards the sides than towards the middle (3). Let us suppose a wheel whose circumference or felloes are of the shape represented in the margin, sloped off on each side, so as to form a right angle or square with each other at the lowest point, or sole of the felloe. If this wheel be made to roll on a flat impenetrable pavement, it will only bear on a point, and move with the least possible resistance. But on substances that yield to its pressure, it acts like a wedge; penetrates deeper than a flat wheel of the same breadth; and partakes of the friction of a double cone; and its pressure tends as much to force the substances on which it acts, *sideways*, as to compress them downwards, and this *lateral action taking place under the crust or surface*, tends to blow up the crust of the road on both sides of the wheel, as far as its pressure extends; and although no wheels are made exactly of this shape, every wheel that has not an equal flat bearing of its whole breadth, partakes of this destructive effect more or less, in proportion as it deviates from a flat smooth circumference.



5. The conical broad wheel rounded cross the felloes, or that has a high streak in the middle, adds this *lateral pressure* to the evils that are inseparable from the conical shape; the one forces up the crust (4), the other grinds the hardest materials; and

no rate of toll can compensate the damage which they do the roads; and it is to be remembered, that in all cases, the *immediate* increase of exertion required of the cattle, is in proportion to the damage done to the roads; and every heavy carriage with wheels of this description, that travels the roads, renders it worse for him that follows: how much then would it be the interest of *all* to use no other wheels, than those that improve the roads?

6. We now come to apply these preliminary observations in determining the most advantageous form of a road (so far only as regards the effect of carriages upon them). As such ample information on this point, and every other matter regarding the laying out, making, repairing, and managing roads, have been given in the several communications to the Board of Agriculture, by Mr. Beatson of Kilrie, Mr. Wright of Chelsea, Mr. Jessop, Mr. Holt, Mr. Joseph Wilks, and Mr. J. F. Erskine of Mar, as would preclude any further observations on the subject, did not an earnest desire of contributing to so important an object of public improvement demand every exertion, and supersede every other consideration.

7. *Convex or barrelled Roads* have been generally preferred; *First,* because they are supposed to lie drier than flat roads, from the declivity on each side, giving a greater current to the water, than could be obtained if carried in the direction of the road; and, *Secondly,* as its *external form* resembles an arch, it is supposed to partake of the same property of sustaining pressure better than any other form; but it must be remembered, that if the abutments that sustain the lateral pressure, and prevent the extension of the best constructed arch, give way, it will no longer sustain its own weight. If then, the convex road be less calculated to resist the *lateral pressure* already described, (4), and to prevent the extension, or spreading of the materials, it can derive no advantage from its apparent affinity to an arch. The advantage of carrying off the water towards the sides is obvious when the roads are just finished, and have their surface of that perfect smooth form which the theory always supposes them to have; but so soon as any ruts are formed, they obstruct the running of the water *towards the sides*, and retain, or conduct it longitudinally on the road, contrary to the original intention; and as no proper means have been used in forming the roads, to carry off the water from those ruts, it remains in them, and is mixed deeper and deeper with the materials of the road by every wheel that passes, till at last the hard protecting crust is worn through, and the wheels penetrate to the soft materials of which the road was originally formed, and deep holes are thus made, which, by the constant passing of all car-

riages in the same track, are enlarged into dangerous gulphs; and all those evils arise from the convex form, which obliges all carriages to drive on the very highest part only; and thus the imaginary advantages of convex roads vanish in practice, and in the place of advantages, we meet with evils of the most formidable nature.

8. When the crown of the convex road is rendered impassible by the constant traffick of all carriages in the same track, if any are compelled to travel on the declivities on either side, the wheels force the hard materials down the sides, (their own weight, and the tremulous concussions of the roads, occasioned by the passing of heavy carriages, also promoting the descent;) the best materials of the convex road are insensibly shifted from the middle to the sides; from the only part of the road constantly frequented, to the extremities, where they can be of no service.

9. *Flat Roads, that are level from side to side*, are much more pleasant to travel than the convex; every part of the whole breadth being equally convenient, is equally frequented, and equally worn, and there being no such declivities, as on the sides of convex roads, the materials have no tendency to shift from the spot on which they are laid (8); no deep ruts are formed, because the road is equally traversed, and the traffick of carriages equally and voluntarily diffused over every part of its surface, and the track of every wheel however shallow, becomes a small channel or drain to conduct the water along the road, in which direction it was intended to flow, provision being accordingly made to gain a proper current, and to carry the water off the road by shallow channels across it, at proper and convenient distances: and here it is to be observed, that as each carriage takes its own course, there being neither rut nor declivity to prevent it, every carriage making new channels to carry the water from the surface of the flat road length-ways, the more carriages that pass, the sooner will the roads get dry; and thus the *frequency of carriages* passing on a *flat road* in rainy seasons has a tendency to keep it dry, and in that respect to improve it; whereas, on a convex road, the frequent passage of carriages tends to its immediate destruction (7); and whoever takes the trouble of observing how the water runs longitudinally in the ruts on a convex road, although the declivity down the sides be incomparably greater than in the direction which it is compelled to take in the ruts, will soon see the propriety of constructing roads so as to have the water run length-ways, upon them, instead of attempting to gain a declivity, by making it run from the middle to the sides.

It may here be enquired, since the water is found to take a longitudinal direction on the convex road, as well as on the flat road, what additional advantage can be

gained, in this respect, by abandoning the convex form in favour of any other? To this it may be answered, that when it is intended to make the water run longitudinally on the road, every advantage is taken for this purpose in the original conducting and formation of the road, which is often neglected when the theoretical advantages of convex roads are admitted; and by avoiding the convex form, we avoid all the disadvantages inseparably connected with it (7), and may gain every advantage that belongs to any other form that may be preferred. But, taking for granted, that the same declivity is longitudinally maintained on the convex as on the flat road, the advantages that must be gained by preferring *the flat* to the *barrelled form*, may be collected from what has been said under each of these heads, all which give a decided preference to the FLAT, over the CONVEX form.

10. *Concave Roads*. Let us suppose a strong trunk, or channel of wood or stone, having its whole length of an equal breadth, and filled several inches in depth with any binding materials, such as are used in making roads, and moistened to such degree as may promote their uniting and cohering. If a heavy cylindrical roller of the whole breath of the channel be made several times to pass on it, the materials not being able to escape sideways from the pressure of the roller, all its force is applied perpendicularly in compressing, consolidating, and bringing the parts into closer contact, and within the sphere of mutual attraction; and as the repeated rolling with the cylindrical wheel cannot in such case promote lateral motion, after the materials have been once compressed, nor any how alter the relative situation of the parts, nor break the texture or retard the induration by any internal relative motion of the parts, the materials will at last become so compact, and *incompressible*, and so rigid, smooth, and close, that the wheel will roll on them with the same facility as on wood, stone, or iron, and if always kept dry, might be almost equal to the best waggon way; but if the resistance to the *lateral action* be taken away, the materials retreating somewhat sideways every time the wheel passes, they can never become so compact and close as when the lateral motion is wholly prevented, and the whole pressure is applied perpendicularly, and when the relative position of the materials are never changed, nor their connection broken.

11. This serves only to shew the necessity of having all roads well bounded with walls, banks, or some other means of firmly resisting the tendency to spread, by the lateral pressure of the wheels that pass upon them; for if the parts of the road have a power of extension, the constant internal relative motion of the parts, however slow or imperceptible, will, by sometimes pressing the one way, sometimes

the other, ever prevent induration, and that complete degree of consolidation and *impenetrability*, which might otherwise be obtained by the traffic of heavy carriages with broad cylindrical wheels. But admitting that a road be consolidated to the greatest degree of perfection, if wheels of the destructive shape described (4) be used with a heavy loaded waggon, they would penetrate its surface, and force the materials to each side; and by the frequent passing of such wheels, the surface must be divided, and the materials broken and disunited to a considerable depth, so as to admit water, which introduces every other means of devastation; and every wheel that has only a partial bearing on the rim belongs to this destructive class.

12. *Roads that are level in the middle*, of a sufficient space for all carriages to drive on, and have an additional space on each side, sloping towards the middle, so as to join the level carriage road, serving to lay on materials from which the *carriage way* is easily supplied, and at the same time serving as an abutment on each side, against the extension and lateral pressure of the materials, and having ditches or drains on the field side of those sloping parts, to intercept springs, and to keep those sloping parts or abutments always dry and rigidly immoveable, may, from every consideration, be reckoned the best construction, having every advantage of the flat road, with the addition of better abutments against the lateral extension, and other effects of such internal relative motion of the materials as may take place by the pressure of a heavy carriage on this, or on that side; for however imperceptible such effects may be, it cannot be doubted that they retard, in a considerable degree, the consolidation, induration, and union of the whole mass.

13. Thus far I have been led, contrary to my intention, to consider the comparative advantages of the different forms of a road, *so far only* as they regard the effects which wheels of different shapes have upon them, and the fitness of each form to resist the effects of such improper shape, and in the hope of shewing the necessity of legislative authority, in preventing the use of any other broad wheels, than such as are truly cylindrical, with a smooth flat rim, and the heads of nails level with the tire.

It can scarcely be supposed that any carter, or waggoner, would prefer a road that was covered with small pebbles fixed to the surface, to a road that was quite level and smooth; yet we frequently see his cart wheel of an immense size and weight, having its rim garnished all round with two or three rows of nails, the head of each projecting above the tire at least three-fourths of an inch. Surely, if the owner of such cart and horses was aware that these projections on the rim of his wheels obstruct the

progress of his horses on the best and hardest roads, and even upon the hardest pavement, as much as pebbles of the same size, fixed at the same distance, on the surface of the roads would retard them, they would entirely discontinue this absurd and ruinous practice.

14. The damage that is done to the roads by locking the wheel of a heavy loaded waggon in going down hill, deserves serious attention; for in dry seasons, this rubbing of the locked wheel crushes the best materials to atoms, and in wet seasons it ploughs up the roads; for whatever may be the steepness of the descent, the rubbing and resistance of the locked wheel will always be the same, and when the declivity is gentle, there is sometimes as much or more exertion required to drag the carriage down hill, as would draw it on level ground when the wheel was unlocked. It would therefore be very desirable, if, to avoid these evils, any other means could be devised of checking the rapidity of heavy carriages in coming down hill, *by a resistance proportioned to the declivity.*

15. Some months since, having occasion to wait on the *Lord Chancellor* on the subject, he shewed me a drawing of a two wheel cart, in which this was effected in a manner that appeared to me equally new, simple, and judicious. On enquiring, I was told that *it was Lord Somerville's invention*, and wishing to mention a matter that was so intimately connected with the subject on which my attention was then bent, and that had so long baffled all the attempts of ingenuity, I waited on his Lordship, and he most politely assented to my mentioning it, in any degree that I might judge most likely to render it useful to the public, or to elucidate any part of the subject which I was then endeavouring to investigate.

16. The *first* thing that attracted my attention in this neat light cart, was a method, equally simple and expeditious, of adjusting the centre of gravity of the load, so as to have a proper bearing on the horse in going down hill, the advantage of which must be obvious to every man of science, more especially with bulky loads, in which the centre of gravity lies high.

17. The next thing, and what was more immediately interesting to me, was a method of applying friction to the side of the wheel, to regulate the motion of the carriage in going down hill, (instead of locking the wheels) the advantages of which method appear to be as follows, viz.

18. *First*, The pressure and degree of friction may with great expedition be adjusted to the steepness of the declivity, so that the carriage shall neither press forward, nor require much exertion to make it follow the cattle.

19. *Secondly,* The friction is with great propriety so applied to the wheel, that a *given* pressure will have *twice* the effect in retarding the progress, that it would have if immediately applied to the body of the carriage, or to the axis: and by applying the friction on both sides of the wheel the risk of heating and destroying the friction bar is much less than if the same degree of friction was applied in one place.

20. *Thirdly,* This apparatus is so conveniently placed, that it can be instantly applied or adjusted, without stopping the carriage, or exposing the driver to the same danger as in locking a wheel.

21. And *fourthly,* This useful contrivance, in which simplicity and ingenuity are so happily blended, will assume yet greater importance, when applied to *both* the hind wheels of waggons, by which means the resistance may always be proportioned to the steepness of the descent, the tearing up of the road prevented, the unnecessary exertion of the cattle in drawing the *locked carriage* down hill avoided, the danger to which the driver is sometimes exposed in locking the waggon wheel totally evaded, and the time now lost in locking and unlocking the wheel, saved.

22. I thought it best here to mention only the general principle and properties of this useful improvement, in hopes that the attempts of different men of genius to obtain the same end may be productive of different constructions, from some of which, useful hints or immediate advantages may be gained, that might be prevented by giving a more particular description in the first instance. I do not know whether this cart has yet been tried, but there cannot exist a doubt of the effect of the mechanical contrivance; the only doubt with me is, whether the constant rubbing of the wheel in descending a long declivity, may not generate a degree of heat, that may occasion ignition; but if ever this should happen, some means may be discovered hereafter to avoid it, and it may always be prevented by a careful driver.

23. Before turnpike roads were so generally established in this country, immoveable obstacles were frequently met with in travelling, to be surmounted by carriages before they could pass. This induced men of science to compute the power necessary to draw a loaded carriage, by the force required to draw it over such obstacles; and as this force was less with high wheels than with lower ones, it appears to have been inferred generally, that the resistance to the progress of a carriage on level roads also, is diminished in the same proportion by enlarging the wheels; and this doctrine in favour of high wheels is maintained by some without limitation, or regard to concomitant circumstances.

24. But we ought to examine, whether in practice there may not be something

to counterbalance this imaginary advantage, when the wheel exceeds a certain size, and whether some disadvantage does not *accompany* the high wheel, that may *increase* the resistance to the progress with the height of the wheel?

25. On turnpike roads, no such obstacles as these alluded to are now to be met with; they are all removed in making the roads; and the resistance to the progress of a carriage, although arising from a variety of mixed causes, is rendered much more uniform, and subject to laws very different from those, by which the resistance of a fixed obstacle to a wheel passing over it, is estimated. The advantages therefore, which high wheels have in surmounting fixt obstacles, vanish when there are no such obstacles to be surmounted.

26. But another advantage yet attends high wheels, even in the improved state of the roads. A high wheel makes fewer revolutions in advancing the same space than a small wheel does; the friction therefore on its axis is less in proportion, as its revolutions are fewer; but although this friction has by some been considered as the greatest resistance to be overcome in drawing a carriage on a well made level road, it does in fact bear no sensible proportion to the resistance at the circumference of the wheel, especially with conical rims.

erroneous

27. *The opposition of gravity in going up hill* is by much the greatest resistance to be overcome on good roads. If then we compare the addition made to *this resistance* by the immense weight of the hind wheels of a large waggon, we shall find it to exceed the whole friction on the axis, out of all proportion; and thus we see, that by using very large wheels much more power may be lost, by adding to the weight, than is gained by the diminution of friction: and although it may be difficult to ascertain the very best height of wheels, under all possible variety of circumstances, it may be best for all carriages of heavy burthen, and that require much strength, to keep the height of wheels within moderate limits, which limits may be much better ascertained by judicious experiments and local circumstances, than by theoretic demonstration.

28. To shew the impropriety of estimating the total resistance to the progress of a carriage, by the force required to draw its wheel over fixed obstacles, it is only necessary to observe, that this mode of estimating is applicable only to such resistances as suddenly raise the centre of gravity of the loaded carriage before it can pass; but all such resistances as are not sufficiently great to elevate the centre of gravity of the

effect.

load, or that have no tendency to raise it, must be estimated by laws arising out of the nature and circumstances of each separate resistance.

29. The several resistances that conspire to retard the progress of a wheel carriage, so far as they occur to me at present, are,

1st. The innate force, or inactivity of matter.

2d. The opposition of gravity in gradual ascents.

3d. The opposition of gravity in getting over fixed obstacles.

4th. The friction in the axis.

5th. The friction, or partial dragging, at the rim of all wheels that are not truly cylindrical.

6th. The resistance to the rim in passing through sludge, or any other such substance, that is partly fluid and non-elastic.

7th. The resistance in compressing non-elastic substances that have no degree of fluidity.

8th. The resistance of substances that have a degree of elasticity, by which they partly recover their position when the wheel has passed, but not sufficiently strong to raise the centre of gravity of the carriage.

9thly and *lastly.* The tenacity or cohesive attraction of substances that adhere to the wheels, such as clay.

30. From a due attention to the very different nature of each of these resistances from each other, the impropriety of estimating the whole, by one general rule must be evident. All that art can accomplish in so complicated a case is, by attending to the nature of each resistance separately; its causes, and the laws by which it resists: is, *to construct carriages that may be the least liable to each resistance, considered separately*; by which means, we may be assured of meeting with the least possible resistance from the whole combined, in all the variety of changes and fluctuations that can happen among them, from the different circumstances of the roads, and of the seasons in the longest journey.

31. In discussing matters of science, I have ever thought that he who is convinced of his mistake, gains the greatest victory; when he corrects an error of judgment, or overcomes a rooted prejudice, he subdues a dangerous enemy, and constant attendant; he is ever after the wiser man, and the more valuable member of society; and

ought rather to be proud of having discovered and corrected, than ashamed of having committed the error.—I shall always consider him as a friend who enables me to correct any mistakes which may have escaped me in the preceding observations; but no regard will be paid to criticisms that have no tendency to improvement, or to public benefit.

Pentonville, March, 1799. ALEXANDER CUMMING.

THE BOARD *having seen* Mr. CUMMING'*s experiments, and resolved to make similar experiments with loaded waggons of full size, with those that he had exhibited with models, applied to him to give the necessary instructions for preparing the apparatus at the Society's expence,—in answer to which, is the following letter:*

MY LORD,

ON a full consideration of the idea of an apparatus to draw a loaded waggon, of the common size, by a weight, I am inclined to think that the experiments would not give the expected satisfaction. The largeness of the weight necessary to draw the waggon, and the shortness of the space which it could be drawn by such an apparatus, would render the experiments made in that way less satisfactory than those made with models, in which the revolutions of the wheels being much more numerous, the difference in the effect with the conical wheels will be more perceptible.

I am well aware, that a suspicion and diffidence may arise in the mind of many sensible persons, who may learn the result of the experiments which have been made at the Board; and who have not seen the experiments and the apparatus with which they were made, or been fully informed of the nature and intent of the conclusions to be drawn from them. But I have that opinion of the sagacity and good sense of the waggon-owners in and near the metropolis, that leaves me no doubt of being able to satisfy the majority of those who may attend the experiments on any future occasion; and when the more sensible and ingenious part are convinced, their example will soon induce the others to adopt, what possibly they might not have sufficient penetration to see the advantage of, without such inducement. But if, after these gentlemen have seen the experiments, any farther proof of the advantages of the cylindrical wheel

should be deemed necessary, to convince them that the conclusions are well founded, and that all the disadvantages that are stated in the Essay and the Appendix, take place in practice, as well as in theory, with every wheel that is not truly cylindrical, I shall always be ready to give any assistance, of which I am capable, in removing their doubts.

If, however, the subject of the public roads of the kingdom should become a matter of legislative investigation, and render a minute experimental proof of every circumstance necessary, I shall be prepared to offer such further experiments and proofs, as will meet every objection, and remove every doubt. But I am inclined to think, that after all that can be done to convince or persuade, that the evil will not be wholly removed without extensive parliamentary regulations.

I trust however, that your Lordship and the Board will believe my readiness to give every assistance in the present stage of the business, as well as to arrange such ideas as may occur to me, as necessary to the accomplishment of all the advantages that may be gained to the public, from a proper system of regulation and management in a business to which my attention has for some years been much directed: and although I have not the vanity to hope, that I can succeed in maturing such a system, the crude ideas that may occur to me, regarding the evils to be remedied, may at least have a tendency to lead others more immediately to the remedy.

I have the honour to remain, with great respect,

Your Lordship's

Obedient,

Pentonville, April 17, 1799.

Humble servant,

ALEXANDER CUMMING.

Rt. Hon. LORD SOMERVILLE.

Board of Agriculture, Sackville Street,
26th April, 1799.

SIR,

BY the resolution of the Board of Agriculture, you will perceive that we are making advances in the very useful path which you have traced out. It was thought by some members of the Board, that the experiments here mentioned for the world at large, in addition to your own, for persons of scientific education, would tend to disseminate that conviction, which cannot fail of being useful to the public.—Will you have the goodness to undertake this commission, which I am sure cannot be given to any person more able to perform it, to the satisfaction of every party.

I remain,

Your obedient servant,

SOMERVILLE, *President.*

ALEXANDER CUMMING, Esq.
PENTONVILLE.

Extract from the Minutes of the Board of Agriculture, 23d April, 1799.

" In consequence of the notice given of a motion by the Earl of Winchilsea, that an " experiment be made with waggons at large, to ascertain the comparative advantages or " disadvantages of conical or cylindrical wheels, and an axle-tree to suit them, for com- " parison with the same waggon and the same load, but with conical axles and wheels, " Resolved that such experiments be made, and that Mr. Cumming be requested to " procure the wheels and axles at the expence of the Board, taking every precau- " tion that the wheels shall be of the same diameter and weight, and the axles of the " same mean diameter, with such other attentions as his mechanical abilities may " suggest; and that such experiment be made on Thursday the 30th of May, on the " road beyond Kennington, in the way to Streatham, at eleven o'clock in the fore- " noon, and that notice be given to waggon-owners, and trustees of the turnpike roads " near London."

My Lord, *Pentonville, Sunday, April 28, 1799.*

I am this moment honoured with your Lordship's letter, accompanied with the extract from the minutes of the Board of Agriculture, of date the 23d.

It is very flattering to me, that your Lordship and the other members of the Board have judged those ideas and experiments which I had the honour of offering to their consideration, so far deserving notice, as to determine them to have an experiment, similar to those which I made in miniature, tried with a loaded waggon of the full size.

I shall ever be ready to exert my utmost endeavours in complying with the desires of the Board, in this, or any other matter that can tend to promote their patriotic views of public improvement, or to overcome deep rooted prejudice. I shall with pleasure undertake the ordering and giving directions for completing the waggon for the intended experiment, but would be glad to state some matters to the honourable Board, before the time for trying the experiment was finally settled or advertised, to prevent any disappointment that might happen by unforeseen delay from the workmen employed: I also wish to have a further communication with your Lordship and the Board, previous to the making the waggon, in order that I may be enabled the better, to meet their ideas and wishes in the intended experiment; for although the general principle and object cannot be mistaken, one mode of making the experiment may be more satisfactory than another; and it is my wish to adopt that mode which may be the most consistent with the ideas of the Board:—I wish it to be particularly decided, whether the wheels of the intended waggon should be of the sizes now used, or of that which may, upon farther investigation, be judged the most proper for general use; upon the idea that the very large size of the hind wheels of waggons, as now made, adds more to the labour of the cattle by the increased weight of the wheel, than is gained by the diminution of friction on the axis; and whether, to render the difference of the resistance at the rim of conical and cylindrical wheels of equal size the more perceptible, any extraordinary means should be used, to diminish the friction on the axles, by using the best *oil-boxes*.

I must confess, that if my best endeavours of eradicating vulgar prejudice was to be exerted without the aid of such powerful and very respectable authority, as the

Board of Agriculture, I would introduce this as a *final experiment*, and shew to some more members of the Board, who have not yet seen them, the experiments on the models, with explanatory observations on the principal object of the experiments, and the conclusions which are meant to be drawn from the result of them; for however great the advantage may be to the draught of cattle, by preferring the cylindrical wheel, *the chief object is the improvement of the roads*; and to impress more fully the many circumstances that lead to these ultimate conclusions, even on the mind of those who are above all prejudice, the experiments and observations should be repeated, and as many objections stated, as may occur to those who attend: it is my wish to meet every objection from those, whose only motive in stating them, is to ascertain the truth; if unable to satisfy them, I certainly am not ripe to encounter public prejudice; if able to satisfy the more judicious and discerning, I shall disregard the opinion of the less intelligent.

I have the honour to remain,

Your Lordship's

Obedient,

Humble servant,

Rt. Hon. Lord Somerville.

Alexander Cumming.

The Board having resolved, on the 23d of April, to make a public experiment with large waggons on the 30th of May, on the road beyond Kennington, applied to Mr. Cumming to order the broad wheels and other requisites for the experiments, which occasioned the following letter:

My Lord, *Pentonville, May 4, 1799.*

In consequence of what passed at the Board of Agriculture on Tuesday, I have applied to two different wheelers to know in what time they could undertake to make the wheels and axles for the experiment which was proposed on the road near Kennington; neither of them could fix any certain time in which they could be done: they say, that all those large wheels are made in the country; that the timber must be cut out for them from

the tree; that there was scarce any chance of getting in London, timber of proper dimensions for making two sets of wheels sixteen inches broad, without making the felloes in two breadths; this would not only prolong the time, but also enhance the expence. I asked them, if they could be finished in the manner which they proposed, in a month? they said, "Not in two;" and on being questioned whether they might be depended on in two months, they said they could not be certain, for the reasons already assigned.

Knowing that when the London tradesmen are employed in any work with which they are unaccustomed, their expences and charge are commonly very high, I made enquiry on that head also, but neither would state his opinion as to the expence, or nearly what they thought it would amount to. I then asked each (separately) what would be the expence of such a waggon, with one set of wheels only, and without the tilt or any of the upper parts above the body of the waggon? the answer was, "Not "less than a hundred guineas." From all which circumstances I thought it improper to give any orders before those circumstances were submitted to the Board.

I am also decidedly of opinion, that other experiments may be made at a less expence, that will tend more immediately and more effectually to overcome prejudice, than the experiment proposed, with wheels that bear only on a part of the breadth of their felloes, and drawn by horses. Since the result of such experiment depends in a great measure upon the nature of the materials of which that part of the road is composed, upon which the experiment is made, and upon the state of moisture and dryness of the materials for some thickness from the surface, a great variety of such circumstances may occur that may very much affect the result of the experiment, although they cannot be discovered by viewing the surface of the road: should any unfavourable circumstance of this kind happen, it might tend to confirm, instead of removing, the prejudice which it was meant to combat. I am clearly of opinion with Lord Winchilsea, that an experiment should ultimately be made with two loaded waggons of equal weight, or with one waggon having occasionally cylindrical, or conical wheels put upon the same axis,* and having the breadth of their rims, and their respective diameters, as equal to each other as possible: an experiment made with such wheels having an equal bearing on the whole breadth of their rim will be decisive, as to the comparative merit of each class of wheels.

With regard to broad wheels that bear on a narrow part only of their breadth, I

* This axis must be susceptible of an adjustment hitherto unattended to, to make it fit for receiving the cylindrical, and the conical wheels, so as to give each a flat bearing on a level surface.

had stated in the Appendix, which I had the honour of submitting to your Lordship and the Board, a case in which they would be drawn with the least possible resistance; that is, with as little resistance as a cylindrical wheel, (see paragraph 4 of the Appendix); and this circumstance may take place, in part at least, from the nature and state of the materials of which the *unknown* road is composed, and which cannot be discovered by inspecting the surface. I must confess that there appears to me to be some risk in making an experiment with wheels that may be thus affected by causes that are invisible to us, and consequently not generally adverted to, and with wheels that have been invented to evade the salutary operation of the laws which were intended to enforce the use of wheels, *whose rims have an equal bearing of their whole breadth*, and whose breadth should be proportioned to the weight of the loaded carriage. Should any circumstance of the nature above alluded to, happen to occur in the proposed experiment with the broad wheel having a narrow bearing, before other means are used to *conquer prejudice*, that *task* may become yet more difficult from the accidental result of an experiment affected by invisible causes:—nor does the experience and success, which I have already had, leave me room to doubt, that by proceeding on the plan which I have proposed, I shall be able to convince at least *nine-tenths* of all the farmers and waggoners, who shall take the trouble of attending the experiments which I may hereafter have an opportunity of making at the Board. Of this I had a pleasing instance on Wednesday: When one of the wheelers already alluded to, called upon me, a gentleman farmer from near Canterbury, of the name of *Hill*, was with me; desirous of seeing my experiments, I invited the wheeler also to see them; and on producing both my carriages, and asking their opinions, which would be drawn with least force, that with the conical, or the one with the cylindrical wheels? they both, without the least hesitation, declared in favour of the conical wheels: I then asked, whether they thought the conical wheel that was straight across the felloe, or that which was rounded at bottom, the best? and they both declared in favour of the rounded bottom, saying, that it certainly *went lighter*.

I then made my declaration in favour of the cylindrical wheel, and proceeded to experiment; but both were so suspicious of deception, that each examined separately the motion of each wheel on the axis, lest any of them should have been screwed tight to prevent the freedom of its motion. When both were perfectly satisfied in that respect, and the waggon loaded, they wished to know if the whole breadth of the conical and of the cylindrical wheels applied equally flat to the road. They again declared

in favour of the conical wheels, and expressed their surprise in strong terms, when they saw the great difference in favour of the cylindrical. They again examined the wheels, yet suspecting that the conical had not the same freedom of motion with the cylindrical; and when they were fully satisfied in that respect, the same experiment was repeated, with the same result, and the same astonishment was again expressed.

With the experiment to prove that the superior resistance with the conical wheel was owing to the different velocities and dragging or rubbing of its rim, they seemed as much pleased as they were surprised at the first, and had the candour to declare, that they never had the least conception of any such resistance; nor that there existed any such cause of resistance at the circumference of the conical wheel, any more than at the rim of the cylindrical wheel; but were then fully satisfied as to the existence of the resistance with the conical wheel, and of the cause from which it arose.

I then observed to them, the derangement which the conical rim occasioned in the materials of roads, and the destructive effects of that derangement, by admitting water through the crust of the road. At this discovery, *Mr. Hill* (the farmer) seemed greatly pleased, and exclaimed, *that although he had been the surveyor of the roads for near twenty years, that he never had thought of that.*

I now began to think that I had completely converted them, and the more so, because they had discovered a proper degree of diffidence and suspicion at first, and in the end declared themselves fully convinced; but when I mentioned the conical wheel with the *high tire in the middle,* I found that I had yet difficulties to overcome, which could not have been accomplished without the preceding experiments and explanations, to prepare the mind by degrees to yield to the conviction of reason.

The *wheeler* insisted, that the wheel having a high tire in the middle, certainly went lighter, than when its whole breadth pressed equally on the surface of the roads; and the gentleman farmer yet thought that the cylindrical wheels would go better when *a little* rounded across the felloe, than if quite flat; because, he said, that if quite flat the whole breadth, it would cut the road quite square at the corners of the wheel; but on calling to their recollection, that the resistance at the rim of the conical wheel was owing to the different velocities of the parts of its rim, and that every wheel that was not truly cylindrical, and consequently truly flat on its whole breadth, must have a different degree of velocity in the several parts of its rim, and consequently partake of the destructive effects of the cone. Having thus satisfied them in the first instance, that the resistance of the conical wheel, was owing to the different velocity of its parts,

the transition from the cone to any other irregular shape becomes easier, and I was enabled to effect that conviction which it would have been vain to have attempted without such previous steps.—I have to apologise for this too long letter; and have the honour to remain with great respect,

Your Lordship's

Obedient humble servant,

ALEXANDER CUMMING.

The Rt. Hon.
LORD SOMERVILLE.

Short Account of EXPERIMENTS *on Broad-wheeled Carriages, exhibited before the Board of Agriculture, on the 18th day of March, and on the 30th of May,* 1799, *by* ALEXANDER CUMMING, *Esq. F. R. S. Edin.*

ADVERTISEMENT.

As many may be disposed to suspect the accuracy of experiments, the result of which, are in several instances, so contrary to general expectation as the following are, it was thought necessary to give a short description of the apparatus, with which they were made; that others, who may incline to try the same, or similar experiments, may prepare an apparatus, with which the same result may reasonably be expected; for any alteration in the apparatus might occasion a different result with the experiment. If, for example, any person was to try the experiment, N° 7, with a carriage having its hind wheels larger than the fore wheels, (as is usual in all four-wheeled carriages) the result would always be different from what is here stated; because the hind and the fore wheels, rolling on the same friction bars, would counteract each other, and be liable to give a different result every time the experiment was repeated, according as the load pressed more upon the hind, or upon the fore wheels. Who-

ever takes the trouble of making himself intimately acquainted with the principles laid down in the preceding essay, may anticipate the effect of every experiment that can be made, under all possible variety of circumstances: and he who is not so completely master of it, as to *recollect*, as well as to understand every part and reference, will always be liable to misconception, and to draw erroneous conclusions from his experiments; and as the number and variety of experiments that might be suggested, for ascertaining the best construction of *wheel carriages*, are endless, Mr. CUMMING has offered only what appear to him as *leading ones*, having a direct tendency to prove the superiority of the cylindrical shape, and to contrast it with the ruinous effects of the conical; and it will afford him much pleasure to find that others should have recourse to such farther experiments and investigations, as may be necessary to convince themselves where his endeavours may have failed. He wishes to recommend nothing but what will stand the test of accurate experiment and sound reason; and it will always be pleasing to him, to see every part of what he has advanced minutely scrutinized; nor will he ever be ashamed to acknowledge any mistake, which he may have made, nor backward in answering any objections that may be stated, if candidly and fairly urged.

N.B. The power required to draw the loaded carriage, in these experiments, will vary, according as the waggon way may be more or less inclined to the horizon. The experiments here stated, were made on a dead level, and repeated on different days, three several times on each day, with the same result each time.

DESCRIPTION OF THE APPARATUS.

THE APPARATUS with which these experiments were made, consisted of two models of waggons, each of which, with its wheels and axles complete, weighed four pounds; and with a leaden weight that was occasionally used (as a load) to either, the loaded waggon weighed thirty pounds.

Cylindrical Wheels.

(1.) The one waggon had *cylindrical wheels*, $2\frac{1}{4}$ inches broad in the rim, and $4\frac{1}{4}$ in diameter: the rims of all the wheels, and the surface on which they rolled, were covered with one thickness of fine woollen cloth, to give an uniform resistance, like that of dust

General View of the Apparatus.

Fig 1	
A.A.	*The Waggon way* .... *(see Parag. 4)*
B	*One of the loaded Waggons* .... *(1. 2 & 3)*
c.c.c &c	*Weights that draw the Waggon* .... *(9)*
D	*The Box which contains the Models, Weights &c and on the top of which the weights that draw the Waggon rest, when the Waggon comes to the beginning of the scale of acceleration* .... *(5)*
	N.B. In each Experim.t the Carriage is brought back so as to begin its motion from the Bar **E**.
Fig. 2	*A side View of one of the friction Bars with the set of rollers that support it* .... *(12 & 13)*
Fig. 3	*Plan of the Waggon way with the friction Bars uncovered and representing the position into which they are brought by the rolling of the Conical wheel upon them* *(12 13 & 31.)*

The figures in parenthesis ( ) refer to the printed paragraphs in which the parts are described.

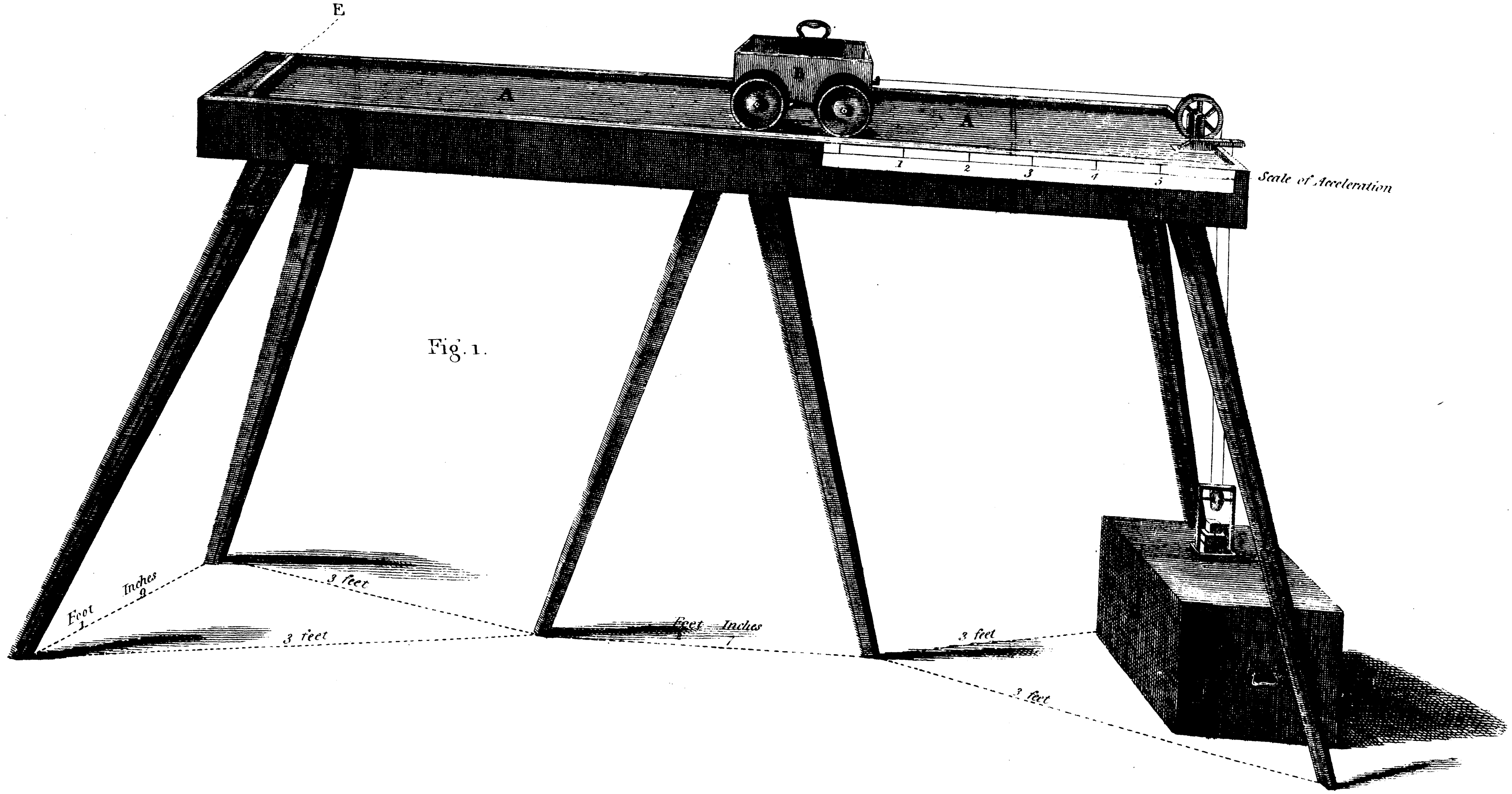
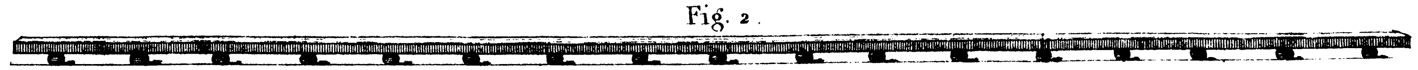


Fig. 1.

Fig. 2.



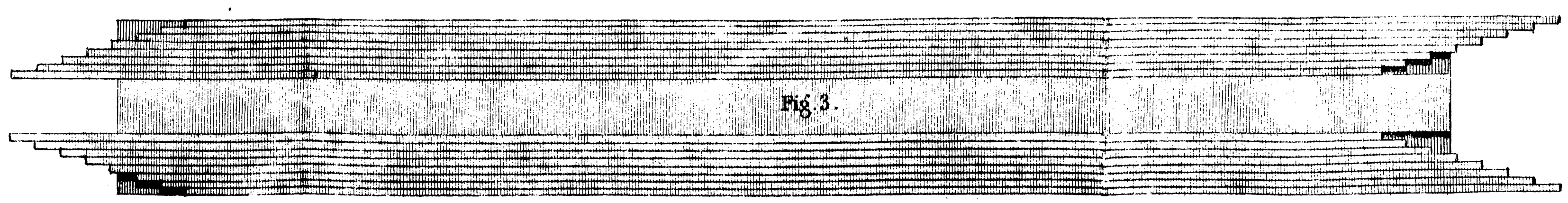


Fig. 3.

S. I. Neele sc. 352 Strand.

or sludge on the roads, and that all the parts of the whole breadth of the wheels might, with the greater certainty, touch, and bear equally upon every part of the surface over which they were drawn.

Axles.

(2.) The axles were made of steel, and the parts that act in the boxes were truly turned, and about $\frac{5}{16}$ of an inch in diameter. They work in brass bushes or boxes, $2\frac{1}{4}$ inches long, and all of them were opened with the same implement, exactly to the same width; so that the axles being fitted to them, must all be of the same size with each other: they were very little tapered, and touched the bushes only about half an inch at each end.

Conical Wheels.

(3.) The breadth or flat bearing of the rim of the *conical wheels* was the same as that of the cylindrical, ($2\frac{1}{4}$ inches,) their greatest diameter, $4\frac{5}{8}$ inches; the least, $3\frac{7}{8}$ inches; difference of the greatest and the least diameters $\frac{3}{4}$ inch; the mean diameter $4\frac{1}{4}$ inches, (equal to the diameter of the cylindrical wheels); the *inside* * of the wheels in both carriages were distant from each other 5 inches, so that both carriages roll on the same track, and every part of the *whole breadth* of each wheel was carefully made to apply equally to the flat surface which it rolled.

(4.) *The path* or *way* on which the carriages were drawn, by means of weights suspended by a fine silk line, was of sufficient breadth for the carriages to roll upon, and seven feet long. Each *carriage* was ten inches long; and the immediate action of the descending weights draws the carriage forward four feet only, so that a space of two feet is left, *for the carriage occasionally to advance, after the descending weights have done acting upon it.*

Scale of Acceleration, how constructed.

(5.) By comparing the space which the carriage advances, after the *weights* have done acting upon it, with the space in which they acted, we discover how much the acting power was greater than the resistance to the progress of the carriage, during the time of their acting; thus, if ten weights, descending a given height, are capable of

* By *inside* is meant the side nearest the carriage.

drawing the loaded carriage a given space, one of these weights, in descending the same height, will draw the carriage one-tenth of that space:—let the space which the carriage is made to advance by the immediate action of the descending weights, be divided into ten equal parts, and, it is evident, that one-tenth of the power, that draws the carriage the whole space, will be required to draw it one of those divisions, (a tenth of the whole space); and if those divisions are continued forward, from where the descending weights have done acting, (which we here call the point of rest) the number of spaces which the carriage advances beyond this point, by the velocity which it had acquired, will shew how much the resistance to the progress of the carriage is less than the acting power; every space or division on this scale, which the carriage advances, after the weights have done acting upon it, being equal in value to a tenth of the weight or power by which the carriage was drawn.—If the resistance to the draught be just equal to the power by which the carriage is drawn, it will stop the instant the weights have ceased acting upon it; but if we find the carriage advance one space on *the scale of acceleration*, (i. e. one space past the point of rest), we conclude that the resistance is one-tenth less than the power; if it advances two spaces, the resistance is to the acting power, as 8 to 10, &c. The numbers in column C of the following table of experiments, refer to this scale, and shew the number of spaces which the loaded waggon advances by its *innate force* (or velocity acquired), when the weights have done acting upon it.

The Fore Wheels and the Hind Wheels of equal size.

(6.) It is here to be particularly noticed, that the fore and the hind wheels, in each model, or carriage, must be exactly of the same size, otherwise the experiments with the friction bars will not succeed: if the fore and hind conical wheels were of different diameters, as is usual in four wheeled carriages, they would have different degrees of rubbing at their rims; and when the hind and the fore wheels roll on the same friction bar, the smaller wheel having a greater tendency to give it motion than the larger wheel, they would counteract each other, and give a result, very erroneous; and different to what is stated in the following experiments.

The Experiment with the Conical Wheels shews only half of the true Derangement.

(7.) It is also to be observed, that the derangement of the materials that is shewn in the *seventh* experiment, represents only *half the damage* that is done to the roads by

deranging and breaking the connection of the parts that form its crust; for either the hind, or the fore wheels alone, that roll on the same bars, would give the same motion to the bars that both the wheels give it; but when they act separately and independently, (as they do on the roads), each will have a *separate effect* in destroying the texture and cohesion of the materials, equal to what is exhibited in the experiment, by *the united action* of the hind and fore wheels together.

(8.) And if the fore and the hind wheels, in the model, (with the conical wheels) were made to roll a double surface, the fore and the hind wheels would *each* exhibit as much motion of the friction bars, as they both do when they roll on the same surface, as in the following experiments.

The Weights that draw the Carriage.

(9.) The loaded waggon, *with the conical wheels*, being placed on its path or waggon-way, a fine silk line was applied to draw it forward, and to this line, (after passing over a pulley) was suspended a thin bag or purse, into which was poured small lead shot, just sufficient to draw the loaded waggon, and to begin its own motion: which weight being divided into ten* equal parts, each of them is supposed to represent one degree, (or one-tenth,) of the whole power; and according to the number of these small weights that are required to draw the loaded waggon under different circumstances, the comparative resistances to its progress are determined.

Nature of the Experiments.

(10.) This apparatus is furnished with different long slips of wood covered with cloth, in those parts only on which the wheels are intended to bear; so that by changing those slips, the wheels may be made to bear on their whole breadth, on the middle only, or on the extremities of the rim; and by making the conical and the cylindrical wheels to be drawn with the same load, on those different slips, in their turn, *the comparative forces that are required to draw the same load on each kind of wheel, under all the variety of circumstances that can occur, may be ascertained experimentally, with sufficient accuracy to determine which principle should be preferred.*

* The ten weights, which together draw the loaded carriage on conical wheels, are equal to a 24th part of the load; and each weight separately, is equal to a 240th part of the weight of the loaded carriage; and by this means, the proportion which the power that draws the carriage bears to the weight of the loaded carriage, may in all cases be found.

Use of the Part of the Apparatus hitherto described.

(11.) This part of the apparatus serves only to ascertain *the comparative degrees of power that are necessary to draw the same load*, under all the different circumstances that may occur in practice, and may be considered as regarding only the *labour of cattle*.—The following part of the apparatus is to represent to sight, and to prove to our senses, the different effects which the *conical* and the *cylindrical* wheels have on the roads; the one in destroying, the other in improving them.

Friction Bars.

(12.) Besides the slips of wood already mentioned (10), there is another *set* of narrow wooden bars, laid longitudinally and collaterally, so as to form one even surface for the wheels of the carriages to roll upon; these bars are covered with cloth also, and each slip or bar is supported by a set of friction pullies, so as to move independently of each other, and with very little friction: seven of these bars lie under the breadth of one wheel, which is made to press equally on each of them; and the friction bars may be fixed, or set at liberty, at pleasure.*

Their Effect in the Experiment.

(13.) *When the friction bars are at liberty*, they move easily on the friction rollers, (12), and when *a conical* wheel is made to roll upon them, (the parts of whose rim necessarily have different velocities,) each bar will comply with the velocity of that part of the wheel that presses upon it; and the different motions of the bars will exhibit to view that difference of motion, or velocity of the several parts of the wheel, that occasions

* To render the relative motion of the friction bars more evident, and to represent the derangement that takes place in the materials of the roads the better, these friction bars are covered with striped cloth (the stripes laid across the road); and when the bars are fixed in their places, the stripes of the cloth join, so as to appear as one entire piece, but when made to move by the rolling of the conical wheels upon them, the derangement of the materials on the road is naturally represented by the relative motion of the contiguous stripes of the cloth.—In all the *preceding experiments*, this part of the apparatus is concealed by a piece of cloth of one colour, stretched tight over the surface of the friction bars, which gives the waggon-way the appearance and effect of one entire piece, or solid bed, for the wheels to roll upon.

the dragging and increase of resistance to the progress of the carriage;—and by fixing these friction-bars, or setting them at liberty, occasionally, the friction or rubbing on the rim of the wheel that rolls upon them, may be removed, or restored at pleasure; and by that means, *its resisting effects* may be separated from all others, its existence distinctly proved, and its quantity accurately ascertained in all possible cases.

Destructive Effects of Conical Wheels on the Roads.

(14.) And by this means also, the destructive effects which this difference in the velocity of the parts of the conical wheels have, in pulverising, breaking, and opening the *protecting crust or surface* of the road, is more convincingly exhibited, and brought more within the comprehension of all capacities, than could be done by lines and demonstration only; and what is here said of the *conical wheel*, is applicable also in some degree to every other possible shape of a rim *that is not perfectly cylindrical.*

EXPERIMENTS WITH THE CONICAL WHEELS.

EXPERIMENT FIRST.

(15.) The loaded carriage *upon conical wheels, having the whole breadth of its wheels flatly applied to the road,* was drawn by 9 weights.

EXPERIMENT SECOND.

(16.) The same loaded carriage, *with its wheels bearing on a fourth part only of their breadth,* was drawn by 6 weights.

OBSERVATION *on the 1st and 2d Experiments.*

(17.) If a conclusion were drawn from the result of these two experiments, it would be, that the *resistance* must always be diminished by narrowing the bearing of the wheel; and increased, by making the *flat bearing* of the wheel, broader:—and it would seem as if *this resistance was inseparable from a flat broad rim.* ∴ Because the Cone was diminished

(18.) OBSERVATION 2d. The preceding conclusion appears so consistent with the general opinion, founded on extensive experience, and attentive observation, that all further enquiry into the cause of this increase of resistance with the broad wheel was totally suspended, as vain and fruitless: and the high tire on the middle of the wheel was

universally adopted by the waggoner, as the only means of removing that increase of resistance, which was found to take place with the flat rim bearing equally on its whole breadth, and which was considered as *inseparably connected* with that flat bearing of the whole breadth.

EXPERIMENT THIRD.

(19.) *The same loaded waggon*, and wheels, bearing only on *two slips or tires at the extremities of the rim*, which together were in breadth only equal to $\frac{1}{3}$ of the breadth of the wheel, was drawn by 11 weights. [illegible]

OBSERVATION *on a Comparison of the 1st and 3d Experiment.*

(20.) Here we see the resistance to the progress of the carriage *increased* by *narrowing* the bearing of the wheel:—when the whole breadth of the wheel pressed equally on the road, the carriage was drawn by 9 weights as in Exp. 1, but in Exp. 3, altho' the bearing is reduced to $\frac{1}{3}$ of the whole breadth, the resistance is increased, and 11 weights are required to draw the same load, that in the 1st Exp. was drawn by 9, and in the 2d, by 6 weights.

OBSERVATION 2d. How repugnant is this to the conclusion that must have been drawn from a comparison of the *first* and *second* experiments only? (17, 18). This experiment proves, that the resistance to the progress of the carriage, and consequently the labour of the cattle, may be *increased*, by making the bearing of the wheels on the road narrower; but the 2d experiment proves, that the resistance and labour of the cattle may be *diminished* by making the bearing of the wheel narrower.

(21.) OBSERVATION 3d. And the joint evidence of these, seemingly repugnant results, proves, That the resistance to the progress of the carriage does not depend altogether on the breadth of the wheel, nor on the flat bearing of the whole rim of a broad wheel; if it did, that resistance must always be increased or diminished, as the part of the rim that bears upon the road was broader or narrower; but this does not happen, for in the 2d experiment, the resistance is diminished from 9 to 6, by making the bearing of the wheel narrower; but in the 3d experiment we see the resistance increased from 9 to 11, by reducing the bearings of the same wheel to one third of its breadth. We must, therefore, examine more minutely, to discover the *true cause* of this fluctuation in the resistance, for it cannot possibly depend upon the

breadth of the wheel, or of that part of the wheel which bears the pressure of the load.

22. OBSERVATION 4th. The greatest *difference of the velocity* being at the extremities of the *conical rim*, that is, at the largest and the smallest parts of the wheel, the *largest part*, if detached from the smallest, would advance in each revolution further than the smaller; but being connected together, the largest part cannot advance without the smallest, which must be constantly dragged forward on the road, a space equal to what it would fall behind the largest in a separated state in an equal number of revolutions; this consideration alone would fully account for the resistance in the 3d experiment being *equal* to the resistance in the 1st;—but the resistance is *greater* in the 3d than in the 1st experiment; because, the pressure of all the load is in the 3d experiment, thrown wholly on the extreme parts of the rim, where the difference of velocity of the parts, and the resistance of this dragging, necessarily become greater, as the weight and pressure on the part or parts that are dragged is increased.

23. OBSERVATION 5th. In the 1st experiment, the pressure is diffused on the whole breadth of the wheel, so that the extreme parts sustain only a third of it:—in the 3d experiment, the whole pressure is confined to the extremities of the rim, where it becomes more intense as the supporting surface is narrower; and owing to this increased intensity of the pressure on those parts of the wheel where the dragging is the greatest, the resistance to the progress of the carriage is greater in the 3d, than in the 1st experiment, in the proportion of 11 to 9.

24. OBSERVATION 6th. And this consideration totally removes all the apparent disagreement between the 2d and 3d experiments: it opens a new field of enquiry; fully accounts for the unexpected result of the 3d experiment, and shews the danger of adopting apparent causes for the real, without recourse to some certain criterion by which they may be distinguished.*

* On some future occasion, if health and leisure permit, I may possibly offer some observations, and state some cases of much importance, where the mistaking the apparent cause for the real, has led to conclusions very erroneous, and unfavourable to improvement. That nothing can be more unfavourable to the progress of improvement, and the investigation of truth, than the imputing an effect to a wrong cause, is evident in the present subject of investigation; where the having imputed the greater resistance, which was found to take place with broad wheels, to the breadth of the wheel, instead of imputing it to the different velocity of the parts of the rim, has stifled all enquiry, and concealed from notice, for more than half a century, the destructive effects of the conical shape of carriage wheels, and has cost the nation some millions of money, in the useless labour of cattle, and extra expences of repairing roads; all which must have been avoided by imputing the resistance in the first instance to the true cause.

EXPERIMENTS WITH CYLINDRICAL WHEELS.

EXPERIMENT FOURTH.

25. *The loaded carriage on cylindrical wheels, with the whole breadth of the wheels bearing on the road,* (as in Exp. 1st.) was drawn by 6 weights.

EXPERIMENT FIFTH.

26. *The same loaded carriage and wheels,* with the wheels rolling on slips of $\frac{1}{4}$ *their* breadth, (as in Exp. 2d.) was drawn by 6 weights.

EXPERIMENT SIXTH.

27. *The same loaded carriage, its wheels rolling on two slips, at the opposite extremities of their rims, and bearing only on a third part of their breadth,* (as in Exp. 3d.) was drawn by 6 weights.

OBSERVATIONS *on the 4th, 5th, and 6th Experiments.*

28. *First,* By comparing these three experiments, we see, that the resistance to the progress of the carriage, on cylindrical wheels, (so far as appears by the number of weights that are required to put the *loaded carriage* in motion) is nearly the same, whether the wheels have a bearing of their *whole breadth* (as in Exp. 4th.)

Or when the wheels bear on a narrow part of the *middle* only, (as in Exp. 5th.)

Or when the wheels roll on two narrow parts, at the opposite extremities of their rim, (as in Exp. 6th.)

29. *Second,* That the same variety of circumstances, which occasioned a difference of 5 weights, (or degrees of power) with conical wheels, (as in Exp. 1st, 2d, and 3d.) did not, by the number of weights, shew any such difference with the cylindrical wheels, (as appears by Exp. 4th, 5th, and 6th.)

30. *Third,* But although no difference of resistance appears by the number of weights that were required to put the loaded carriage, on cylindrical wheels in motion ; it appears by the number of spaces which the carriage advances, in each experiment, after the descending weights had done acting, (see column C.), that the *resistance* to the progress of the carriage was the least, when the bearing of the wheels was the broadest; as will appear more fully, when the use of the scale of acceleration is explained.*

* This scale had not been applied to the apparatus, nor thought of, when the experiments were

The following Experiments are intended to shew the very different Effects which the conical and the cylindrical Wheels have on the Roads, and are particularly recommended to the Notice of the Trustees of Turnpike Roads, as well as to those who are interested in the Use of broad Wheels.

31. The same carriages that were used in the former experiments, are used in the following also; but they are now drawn upon a path-way that is composed of narrow wooden bars, of the whole length of the frame, supported on *friction rollers*, (13), which bars being *set at liberty*, remove nearly the whole friction from the circumference of the wheels; and when the *bars are fixed*, the friction at the rim is again restored.

N. B. The breadth of each wheel covers seven friction bars, and presses equally on each.

EXPERIMENT SEVENTH.

32. The loaded carriage, with *conical wheels*, their whole breadth bearing equally on the friction bars (13), (now *at liberty*), and the friction by that means being removed from the rim, was drawn by 6 weights.

OBSERVATION *on the 7th Experiment.*

33. In this experiment, each of the narrow bars, on which the wheels were drawn, is moved with ease on the friction rollers, and each bar complying with the motion of that part of the wheel that pressed upon it, the difference of the velocities of the several parts of the wheel is thus transferred to the bars; and the relative motions of

made before the Board of Agriculture; and from an attentive comparison of the experiments that have been made with the conical wheels, (the 1st, 2d, and 3d,) with those similar ones that were made with the cylindrical wheels, (the 4th, 5th, and 6th), it will clearly appear, that the increased resistance, which has hitherto been found to take place with broad wheels, was NOT owing to the *breadth*, but to the *conical shape* of the wheels; and that by making the rim of *carriage wheels* of a true cylindrical form, their breadth may be increased, and the whole breadth have an equal flat bearing on the road, without increasing the resistance to the progress of the carriage, but, on the contrary, that the labour of the cattle will be diminished by increasing the breadth of the wheels.

the bars represent the difference of the velocities of the parts of the rim that pressed upon each; and exhibits also the manner in which the materials of the roads are disunited, and broken, by every conical wheel, wherever it rolls, and as often as it rolls in the same place.—This experiment also proves past all dispute, that the increased resistance with the *broad conical wheel,* arises from the different velocity of the several parts of the rim, and the dragging and rubbing occasioned thereby, (as fully explained in the essay on that subject); for, when this friction, or dragging, is removed (by setting the friction bars at liberty), the conical wheel is drawn nearly with the same facility as the cylindrical (see Exp. 4th and 7th); but when the dragging on the rim is again introduced, (by fixing the friction bars), the resistance becomes as great as when the conical wheel rolls on the whole breadth of its rim, on one solid bar, (as in Experiment 1st).

EXPERIMENT EIGHTH.

34. The loaded carriage, with the *cylindrical wheels* placed upon the same friction bars, was drawn by 6 weights.

OBSERVATIONS.

35. *First,* But no motion of the friction bars took place, (although at liberty to move) because the motion of every part of the cylindrical rim was the same; each had an equal propensity to advance, and there was no dragging, rubbing or counter-action on the rim.

36. *Second,* By comparing this experiment with No. 7, it appears, that when the friction arising from the different velocities of the parts of the *conical rim* was removed, the carriage with the conical wheels was drawn by the same number of weights as with the cylindrical wheel, (in Exp. 4th, 5th, and 6th): this also shews, that the resistance does not depend upon the breadth of the wheel, but upon the unequal velocity of its parts, arising from an improper shape; for where there is no difference of velocity (as with cylindrical wheels), there is no motion of the friction bars, because the wheels roll upon them with more facility than the bars do on the friction rollers.

EXPERIMENT NINTH.

37. *The friction bars being fixed,* the carriage with the *conical wheels* was again drawn on the same bars, by 9 weights, *the same as in the first experiment, when the whole breadth of the wheel had an equal bearing on the road, and the rubbing on its rim took place.*

38. This proves that the *difference* in the result of this experiment, and No. 8, arises *solely* from the rubbing at the rim of the conical wheels, all other circumstances being perfectly alike in both experiments.

EXPERIMENT TENTH.

39. *The friction bars remaining fixed*, the carriage with the *cylindrical wheels* was drawn, (as in Exp. 8th), by 6 weights.

Observations.

40. *First*, These two last experiments tend only to corroborate the 7th and 8th experiments, and prove, that the resistance on this path (composed of narrow bars, supported on friction rollers), is exactly the same, when the motion of the bars is stopped, as on the solid bar, (in Exp. 1st and 4th); and by comparing Exp. 7th, 8th, and 10th, we see that the *cylindrical wheel* moves with as much facility when the friction bars are fixed, as when they are at liberty, because there is no rubbing or difference of velocity of its rim, to move the bars, as with the conical wheel.

41. *Second*, It appears, by comparing the 1st experiment with the 4th, and the 9th with the 10th, that under the similar circumstances of these experiments, the increase of resistance at the *conical rim*, occasioned by the rubbing which arises from the different velocity of its parts, is equal to three degrees of acting power, or three-tenths of the whole resistance that the loaded carriage meets with on a *level path* (9), covered with a moderate quantity of dust or sludge; but this difference will not be so great with large, as with small wheels.

42. *Third*, In the first six experiments we see how much easier the same load is drawn upon cylindrical, than upon conical wheels; and consequently how much it is to the advantage of *the waggoner* to prefer the former to the latter; since, by that means, fewer cattle can draw the same load; or, if the same number be employed, the exertion required of them will be much less.

43. *Fourth*, The 7th, 8th, 9th and 10th experiments prove, that the increased resistance with the conical wheel, arises from the different velocities of the greater, and of the smaller parts of its rim : they exhibit to our view also, the destructive effects of the conical wheel, in grinding, breaking, and loosening the materials of the roads, as stated in paragraph 32, of the preceding essay : and this shews how much it is the interest of the *Trustees of Turnpike Roads* to discountenance the use of conical wheels.

Explanation of TABLE *of* EXPERIMENTS.

44. In the following TABLE, the results of all the experiments are exhibited at one view, but in a different arrangement from that in which they were made: in order that those under similar circumstances with the conical, and with the cylindrical wheels, might be brought together, and more easily compared.

45. The first column in the table, (marked A.) gives the number of each experiment according to the order in which they were made, that reference may, if necessary be made to them.

Then follows a description of the circumstances under which each experiment was made.

46. In the column B, is given the number of weights required to draw the carriage, under such circumstances, so as just to *begin its motion* without assistance.

The column C shews, on the scale of acceleration, the number of spaces which the carriage advances, (5), after the weights have done acting upon it;—and estimating each division on this scale as equal in value to *one-tenth of the weights that draw the carriage* (5), we ascertain how much the resistance to the progress of the carriage is less than the power by which it is drawn, *in decimals of that power.*

TABLE OF EXPERIMENTS.

A. Number of the experiments according to the order in which they were made.	The circumstances under which the Experiments were made, with the different sets of wheels.	B. Number of weights required to make the carriage begin its motion.	C. Number of spaces which the carriage advances after the weights have ceased acting.
1st.	The CONICAL WHEELS bearing on their whole breadth, were drawn by - - -	9	$0\frac{1}{2}$
4th.	The CYLINDRICAL WHEELS, do. do.	6	$3\frac{1}{2}$
2d.	The CONICAL WHEELS bearing on a fourth of their breadth on the middle tire - - -	6	1
5th.	The CYLINDRICAL WHEELS under the same circumstance - - - - -	6	2
3d.	The CONICAL WHEELS bearing on two slips on the extremities of their rims - -	11	0
6th.	The CYLINDRICAL WHEELS under the same circumstances - - - - -	6	$2\frac{1}{2}$
7th.	The CONICAL WHEELS drawn on friction bars, that remove the friction at the rim - -	6	$0\frac{1}{4}$
8th.	The CYLINDRICAL WHEELS on do. at liberty, but the friction bars do not move - -	6	1
9th.	The CONICAL WHEELS on the friction bars (fixed) bearing on their whole breadth -	9	$0\frac{1}{3}$
10th.	The CYLINDRICAL WHEELS do. do. -	6	$0\frac{2}{3}$

A RECAPITULATION *of the Effects with each Class of Wheels, from a Comparison of the similar Experiments made on each Class, as stated in the preceding Table.*

By the *first* and *fourth* experiments it appears, that the same load that is drawn on the *conical wheels*, by a power of nine, is drawn on *cylindrical wheels* by a power of six; and

That after the *power* has ceased acting, the carriage with the conical wheels advances only one *half a space*, on the scale of acceleration; but the carriage with the cylindrical wheels, although drawn by one-third less power, has sufficient *motion* left to carry it forward *three spaces and a half*, after the descending weights have done acting upon it.

By the *second* and *fifth* experiments it appears, that when the conical wheel is made to bear on a fourth part only of its breadth at the middle of the rim, it is drawn by a power of six, and advances *one space* after the power has ceased acting;—but the *cylindric wheels*, bearing on the same portion of their breadth, and drawn by *the same power*, advance on the scale of acceleration, *two and a half divisions*, which proves, that even the *narrow cylindrical* wheel is drawn easier than the narrow conical wheel, and that the difference in favour of the narrow cylindrical wheel is, in this case, equal to $\frac{3}{20}$ of the power by which the carriage was drawn.

The *third* experiment shews, That when the *conical wheel* bears equally on the opposite extremities of the rim, *eleven weights* are required to draw it; and with this increased power, it stops the instant that the descending weights cease to act upon it; the uniform resistance to its progress being equal to the uniform action of the power, leaves no residue of motion to carry it forward.

The *sixth* experiment shews, that with the cylindrical wheels bearing in like manner on the extremities of their rims, *the same load* was drawn by *six* weights only; and the motion was so much accelerated as to carry the waggon forward two and a half spaces, after the weights had done acting on it.

And the result of all these experiments prove the following facts, viz.

THAT, the greater resistance which takes place with the broader conical wheels, does not depend upon the breadth of the rim alone, but upon the breadth and the conical shape jointly.

THAT, in conical wheels, the *increase of resistance* depends upon the difference of the velocity of the greatest, and of the smallest parts of its circumference, (Exp. 3.) and the exertion of the cattle will necessarily increase in the same proportion.

THAT, the resistance is increased on the same conical wheel, when the pressure of the load is confined to those parts of the rims that have the greatest difference of velocity, (Exp. 3.)

THAT, on the same principle, the resistance with the conical wheel *on a hard bottom*, is diminished by narrowing its bearing; but on yielding substances the effect is the direct contrary, (Exp. 2d, and 3d.)

THAT, since this friction and dragging of the conical rim is owing to the different velocities of the several parts of the circumference, it follows,

THAT every wheel which has not an equal velocity in every part of its circumference, must have a dragging and unnecessary resistance, that is, a resistance that may be avoided by giving to every part of the circumference, or rim, the same degree of velocity.

THAT, the only means by which an equal degree of velocity can be obtained in every part of the circumference of a wheel, is, by making all the parts exactly of the same diameter; and every wheel that has all its parts of the same diameter, must necessarily be *cylindrical*. And thus we see,

THAT the conclusion from the result of experiments, and from the theory stated in the preceding essay, concur in proving, that so far as regards the labour of cattle, or the facility of the progress of carriages, the cylindrical shape of a wheel is preferable to any other possible shape.

47. And this superiority of the cylindrical wheel, which has hitherto been illustrated by considering only the causes from which the greater resistance with conical broad wheels arises,* is further corroborated by the experiments that have been made with the cylindrical wheels, viz. the 4th, 5th, and 6th, in each of which, *the same number of weights* were required to make the loaded carriage begin its motion, under the same variety of circumstances, which with the conical wheels occasioned the following difference in the number of the weights required to draw the same load, viz. 6, 9, 11, (see the Table, Exp. 2d, 1st, and 3d, column B.) and the number of weights that were capable of drawing the loaded carriage under each of those various circumstances on

* See Experiments 1st, 2d, and 3d.

the cylindrical wheels, was only equal to the least that was required with the conical; and when the conical wheels bear on the extremities of their rims, 5 more weights are required with them than with the cylindrical wheels, (see Exp. 3d and 6th.)

48. And although no difference appears by the number of weights required to begin the motion of the carriage with the cylindrical wheels, whether they bear on the whole breadth of the rim; on a narrow part of its middle; or on the extremities of the felloes; it appears by the spaces which the carriage advances, on the scale of acceleration, (column C.) after the weights had done acting upon it, that

49. When the cylindrical wheel bears on its whole breadth, it advanced on the scale of acceleration, $3\frac{1}{2}$ spaces;* when bearing on one-third of its breadth only, it advanced only $2\frac{1}{2}$ spaces; and when bearing on a fourth of its breadth only, it advanced no more than 2 spaces: here then, we discover a most important difference between the cylindrical and the conical wheel; namely that *the broader the bearing of the cylindrical wheel,* the more easily it advances, and the broader the bearing of the conical wheel, the greater is the resistance to its progress.

50. How much this *peculiar property* of the cylindrical wheel ought to recommend its use to THE FARMER, and the great advantages that may be derived from it, in preference to any other possible shape, for agricultural purposes, will best appear from the following concluding paragraph in the address of LORD SOMERVILLE to THE BOARD OF AGRICULTURE, on its meeting, the 27th of November, 1798.

51. "PREJUDICE apart, any system which embraces economy, and, that which is "of more importance, *dispatch in labour,* must be held up, under whatever form it "may present itself; *to enforce the good policy of* SEIZING THE MOMENT WHEN "GROUND IS IN TEMPER FOR WORKING, IS THE BASIS ON WHICH CROPS VERY "MUCH DEPEND. By the joint effects of precept and example, to stimulate men to "new efforts, by crying down with impartiality systems founded in error, and holding "up to public view such as merit imitation, *the Board of Agriculture* will fulfil the "purpose of its institution, and stand high in the estimation of every man who loves "his country."

52. If the carrying manure on cultivated, and on meadow lands, in all seasons, be an object within the scope of this excellent principle, how can it be better effected than

* And here it is to be recollected, that every space on this scale is equal in value to one-tenth of the power by which the carriage is put in motion, (5).

by using light carts, *on low cylindrical broad wheels?* and the wheels being of small diameter, will facilitate the loading; and they may be made of considerable breadth without any great addition to their weight; and as the resistance to the cylindrical wheel is not increased by increasing its breadth, and since the depth of the impression which it makes on soft earth is diminished by increasing the breadth of the wheel, much advantage must arise to the FARMER by using broad light cylindrical wheels for all the purposes of farming, as well as for those carriages that frequent the roads only.

53. Having now endeavoured to prove that the use of cylindrical wheels must be advantageous to the WAGGONER, not only by diminishing the labour of his cattle on *the same road*, but also by keeping that road in a constant state of better repair;—that it must be advantageous to THE TRUSTEES of the roads, by preserving and improving the roads, so as to be kept in better repair, at a less expence;—that independent of the consideration of the public roads, it is equally the interest of THE FARMER to use broad cylindrical wheels, of a reduced size and weight;—if those facts which I have endeavoured to establish, with regard to the WAGGONER, the TRUSTEE, and the FARMER, be admitted, the universal use of carriage-wheels of a light construction, and with *broader* flat rims than are now used, will be universally adopted; which must very much improve the roads, diminish the expence of keeping them in repair, and increase the safety, pleasure, and expedition of travelling.

54. It cannot then be doubted, that every indulgence that can tend to encourage a more general use of heavy carriages, and cylindrical wheels, of a breadth proportioned to the number of horses (or other cattle) employed in drawing them, must be highly beneficial to the roads, and may ultimately be rendered advantageous to the public in a greater degree than has yet been mentioned; but, least I should exhaust the patience of *the Board of Agriculture*, I conclude for the present, with expressing my readiness to answer any objections that may be made *in writing, and signed with real name and address*; and to acknowledge any hints that may be communicated for further improvement or illustration; and if I have not been so fortunate as to offer such experiments, or to use such reasoning as to be universally understood, many other means may yet be suggested to illustrate a subject which appears to me to acquire additional importance with every step in the progress of its investigation:—but admitting that experiments could be devised, that must convince every person who *sees* them, unless that information be communicated to all those to whom it might be useful, and to whom, it might be equally advantageous to the public to have it communicated, the intended good purpose will be frustrated.

55. Fully convinced as I am of the patriotic exertions of the Board of Agriculture, and highly sensible of its very flattering attention to my endeavours on this occasion, and of the powerful effect which its example and recommendation must have on the public mind, I am nevertheless of opinion, that the advantages that may be derived to the public from the management and improvement of the public roads, can never be obtained to the full extent, without a revisal of the turnpike laws, and new regulations regarding the formation of the roads, and construction of carriages, &c.

Pentonville, June, 1799. A. CUMMING.

The following Letter was thought the more worthy of insertion, from the attention which Mr. Upton paid to the Experiments, the shrewd observations he made, the reluctance with which he appeared to give up an opinion founded on long experience and attentive observation; and, lastly, from the candour with which he expressed his surprise at the result of the experiments, and acknowledged his entire conviction of the justness of the conclusions.

Mr. CUMMING,

SIR,

As under is the copy of a letter I mean to forward to Mr. JUDD of Banbury; if I have made any mistake respecting the *power* (if you please, horses), I will esteem it a favour that you will let me know.

Your humble servant,

June 1, 1799.

THOMAS UPTON,
No. 27, Rodney-street, Pentonville,
Late of the Bell Inn, Warwick Lane.

Mr. JUDD,

SIR,

ON Thursday last I attended the Board of Agriculture, to see an experiment on waggons, drawn on the principle you and most carriers in the kingdom use—this experiment was made by a Mr. Cumming, the magistrate of our village, where we

sometimes meet. We had previously been talking on the subject, but I never would have believed it, had I not seen it. Owing to the advertisement being worded in such technical terms, it never caught the eye of men interested in the business, and few persons in the business attended besides myself. When I was asked my address, I told them the truth, but added, in behalf of you. One of the members, (a Mr. Stratton, of Great Tew) who, I believe, knows you, was very polite to me;—he saw I was deaf, and brought me a chair into the middle of the room, and desired Mr. Cumming particularly to address me.

A waggon in miniature like yours, 16 inches, (but flat on the sole) was set agoing, which required 9 horses to draw it;—the same waggon was set a going, with *a high tire* on the middle of the sole of the wheel, and which was drawn much quicker with 6 horses. Now all this was nothing new to me, or you: then a high tire was put on the inside and outside of the sole of the wheel, and taken off the middle of the wheel; it then required 11 horses to draw it; this, at first sight, I thought a useless experiment:—then a waggon was set off with the same load, on 16 inch wheels, quite cylindrical, like a garden roller; now this waggon only took 6 horses to draw it, which, I confess, much surprised me; then a high tire was put on the middle of this wheel, and I expected of course it would have gone with less power, but it then required 6 horses to draw it, and with more difficulty. The Board saw I was struck with these two experiments, and begged I would communicate any ideas of doubt.—I begged the last two experiments might be performed again, which was done with politeness. After that, the high tire was put on the inside and outside rims of the cylindrical wheels, and taken off the middle, and 6 horses drawed it again;—this experiment did not then seem to me of much consequence, and some of the Board were going away, supposing all was over; but Mr. Cumming had a new turnpike road for these waggons to move on, which shewed and explained all the causes,—I wish you had been there to have seen it: I am doubtful of being able to explain it by pen and ink, but if I should not, it is not the first offence.—This road had two tracks, where the wheels of both waggons went on, that would give way, backwards or forwards, in a horizontal line, and when the waggon with the wheels of the conical form, or generally called *dished,* was used, that part of the road, where the largest part of the wheel passed, was thrown back, while that part where the outside passed on was thrown forward, evidently shewing, that those wheels are very injurious to the roads, as well as to the horses. The other waggon with cylindrical wheels, like a garden roller, made no

difference at all: but if you will reason but five minutes, it is very plain;—suppose a wheel of the size of the inside rim of your rollers, another wheel of the size of the outside rim, the smallest will go round much oftener than the largest betwixt London and Banbury; then, suppose them both put on one axle-tree, but so screwed together that both must turn together, must they not counteract each other against the power that moves them, as well as the ground it moves on? nothing so plain. And, farther, it proves that wheels truly cylindrical, go with less power that are widest on the sole.

Mr. Cumming hath promised me, if any number of carriers will attend, to shew these experiments.—I believe it is no uncommon thing for farmers, when the season hath been very wet, and dung is wanted on the land, to send the broadest wheeled cart they have, for two causes, viz. the narrow wheels would sink in and cut up the ground, and of course would be harder to draw.

Your's sincerely,

THOMAS UPTON.

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